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A COMPARISON OF VERBAL, MANUAL, AND CONDITIONED-RESPONSE METHODS IN THE DETERMINATION OF AUDITORY INTENSITY THRESHOLDS

BY CLAUDE C. NEET

Clark University

I. PROBLEM

The present study [1] is an investigation of the comparative sensitivities of four different response mechanisms when used as determiners of auditory sensitivity. Absolute auditory intensity thresholds have been determined by verbal, manual, conditioned respiratory, and conditioned eyelid responses by three different procedures which have enabled a comparison of these methods of report. Briefly the results indicate that the verbal form of response and the conditioned eyelid reflex yield lower thresholds than either the manual response or the conditioned respiratory gasp; the results therefore further indicate that the status of the response, as conditioned or non-conditioned, has in itself no effect on the threshold level.

II. APPARATUS AND SUBJECTS

The apparatus consisted essentially of an adequate sound-reducing room six-feet high, six-feet long, and four-feet wide; sound sources for producing tones of constant frequency but controlled, variable intensities; headphones; pneumograph; devices for recording manual, verbal, conditioned respiratory and conditioned eyelid responses;

[1] The author is indebted to Professor W. S. Hunter for guidance during the experimentation which was performed at Clark University from October 1933 through July 1934.

and devices to produce and administer unconditioned stimuli. A Seashore Audiometer, producing a tone of 120 cycles per second, was used in the first part of the experiment and a General Radio Company Beat Frequency Oscillator, type 613-B, with a variable air condenser, type 539-A, and a 6000-ohm attenuation box having a range of 0 to 60 decibels was used in the latter part of the experiment. The Oscillator was set to produce a tone of 500 cycles. Two earphones were used throughout the investigation. Only one of the phones was activated; the other served to cover the ear not in use. The activated phone was that which accompanied the Seashore Audiometer. The same ear was used each time, and the earphone was placed, as nearly as possible, in the same position each day.

A telephone circuit from subject to experimenter was established so that when the subject spoke into the transmitter the experimenter could readily hear the verbal report. In the simultaneous-response procedure the subject's verbal report was recorded by having him speak into a voice key which was electrically connected to a writing point on the recording drum. The manual report recording devices consisted of two simple telegraph-key switches, one located near the subject's right hand and one near his left. Each switch was connected in series with batteries and a 2.5-volt light bulb placed on the experimenter's panel. A slight pressure on either switch by the index finger caused the corresponding light to flash.

A small rubber balloon pneumograph (placed at about the level of the fourth rib, just over the heart, and held in position by a leather belt), attached to a Marey tambour and writing point, served to record the subject's breathing. An electric shock, the unconditioned stimulus used to establish the conditioned respiratory response, was administered by two insulated thimble-electrodes tied on the index and middle fingers of the subject's right hand. The 120-cycle house circuit, shunted through a 1750-ohm Jagabi rheostat and led to a single-throw knife-switch, served as the source of the shocking current.

The lid recording device was somewhat similar to that used by Cason (2) and was designed to record electrically the occurrence of any lid response of normal amplitude. It consisted essentially of a band of brass about 1¾ inches wide which fitted around the forehead and was fastened in place by two adjustable, elastic bands, one of which passed from the ends of the brass band around the back of the head, and the other of which passed over the head from front to back. Fastened to the headband just above the right eye was a small adjustable right-angle brass rod at the end of which was a small, grooved, horizontal strip which served as the fulcrum on which the lid lever rested. The latter consisted of a fine copper wire five-inches long, one end of which was beaten and twisted into a small hook which fastened to a small gummed paper loop stuck to the subject's upper eyelid just above the eyelashes. The other end of the lever was flattened to enhance the necessary electrical contact. The lid lever was so constructed and balanced that its movement was not noticeable to the subject. Fastened to the center of the headband was an adjustable brass electrode which extended out over the lid lever in such a position that, when the lid winked, the opposite end of the lever would rise and strike the projecting brass electrode, thereby making an electrical contact. The device was efficient and recorded every wink of at least normal size. The unconditioned stimulus used to develop the conditioned wink was a momentary puff of air projected onto the subject's right cornea through an adjustable copper-tube jet fastened to the headband. The copper jet was connected to a small pneumatic bulb placed on the experimenter's panel. A rapid blow applied to a lever of fixed excursion caused the bulb to be compressed and in turn a short puff of air of constant volume to be expelled.

Ten different subjects were used in the investigation. All were naive concerning the nature of the experiment except B.N. and C.N. The former was the experimenter's wife. She served as subject throughout the entire investigation and also served as experimenter while C.N., the usual experimenter, was a subject. All subjects were males except B.N.; all were mature college undergraduates or graduates and none possessed any noticeable auditory defects.

III. Procedure

The general method was that of determining absolute auditory thresholds, using a modified method of limits, by four different response mechanisms: (1) verbal report, (2) manual discrimination report, (3) conditioned respiratory gasp, and (4) conditioned eyelid response. These four types of report were arranged in three different procedures so that practice effects would be at a minimum and so that comparisons of the different methods of report would be as accurate as possible. These procedures were: (1) rotation, (2) combination, and (3) simultaneous response. The thresholds in the rotation and combination procedures were determined by verbal report, manual discrimination, and conditioned respiratory gasp. Thresholds for the simultaneous-response procedure were determined simultaneously by a verbal report and a conditioned eyelid response. All threshold determinations were made during daily experimental sittings of approximately one hour each, during which the subject was seated in the darkened sound-reducing room, the experimenter being outside. Each subject was given a preliminary sitting to accustom him to the apparatus, to determine which ear was to be used, to determine his approximate threshold, his general sensitivity to the electric shock, and to acquaint him with the experimental routine.

Methods of Report.—The routine of the verbal report was as follows: The subject was seated comfortably, in the chair at the small desk in the sound-reducing room, with the telephone mouthpiece in place and headphones adjusted. The instructions repeated to him orally were: "When you are sure that you hear the tone, say 'yes' into the telephone transmitter. *Do not guess.* Report 'doubtful' only when you are uncertain." Descending and ascending series were then presented. The simultaneous-response procedure involved a verbal report in conjunction with a conditioned eyelid reflex to determine thresholds. The verbal-report procedures and instructions were exactly the same as those described above, except that the subject was asked to speak into a voice key instead of into the telephone transmitter. No instructions were given the subject concerning the activity of the eyelid which had been conditioned just prior to the threshold determinations. The instructions for the manual discrimination method were as follows: "When you are sure that you hear the tone, press the key at your right hand momentarily with your index finger. *Do not guess.* Report 'doubtful' by pressing the right and left keys."

The procedure of conditioning the subject's respiratory gasp was very similar to that followed by Garvey (3). The conditioned stimulus was presented for a period of three seconds at the termination of which the shock was administered for approximately 0.2 sec. There was an overlap of the tone and shock of about 0.1 second and the tone-shock presentations were administered at 27-, 42-, 57-, and 72-second intervals in random order. The conditioning procedure was continued until the subject gave definite evidence of being stably conditioned, at which time threshold determinations were begun. In determining these by the conditioned respiratory gasp and by the conditioned eyelid response, the tone was reinforced by the appropriate stimulus in the descending series only so long as the subject continued to respond to the tone.

Tones in the ascending series were not reinforced until the subject responded to the stimulation. The usual form of the conditioned respiratory gasp is shown in Fig. 1. Practically every subject gave responses which were well differentiated from the normal breathing.

The subject's eyelid response was conditioned to the 500-cycle tone. Preliminary recordings were made of the subject's normal rate of winking and of the effect of the conditioning tone on the winking rate. In no case did a sound of appreciable loudness

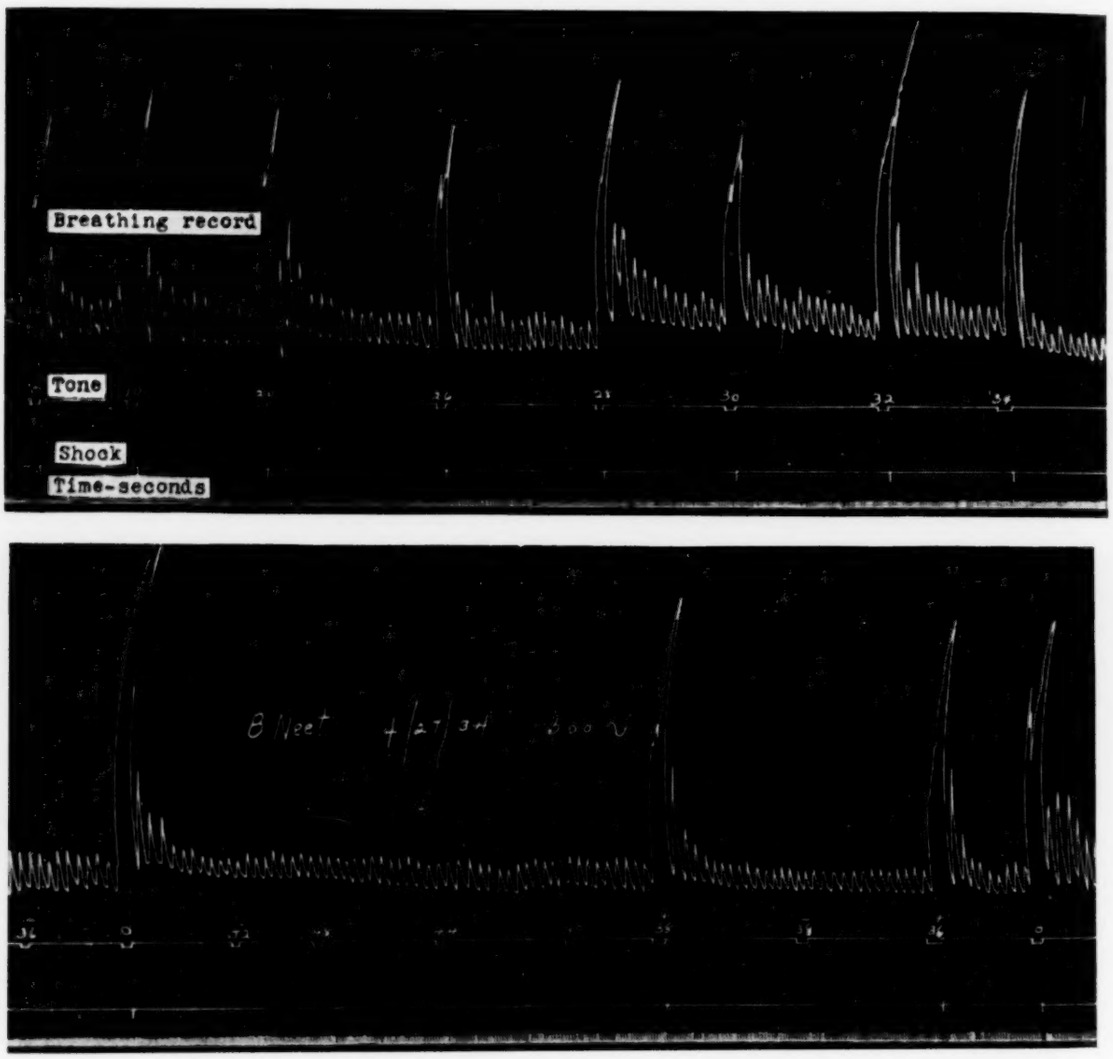

FIG. 1. Record showing the usual form of conditioned respiratory response.

(0 attenuation) have any effect. In the conditioning procedure the tone was presented for three seconds. Just as the tone was withdrawn, and so that there was an overlap of about 0.1 to 0.3 sec., a short puff of air was projected on the subject's cornea. A typical reflex wink, thus elicited, is shown in Fig. 2. This procedure was repeated at intervals of 27, 42, 57, and 72 seconds in random order until the lid response was stably conditioned at which time threshold determinations were begun. These determinations were made in exactly the same manner as were the conditioned respiratory-gasp thresholds.

Specific Procedures.—The rotation procedure was designed to determine thresholds during consecutive daily sittings by one method of report, then during daily sittings by a second form of report, and finally by a third type of response. Six subjects were tested by this procedure, two according to the order—verbal report, conditioned response, manual report; two by the order—manual, verbal, conditioned response; one subject by the order—conditioned, verbal, manual; and one subject by the order—conditioned, manual, verbal response.

Six subjects, three of whom had been used in the rotation procedure, were used in the combination procedure. The verbal and manual methods of determining thresholds were used twice in alternation during the one-hour daily sitting. On alternate days,

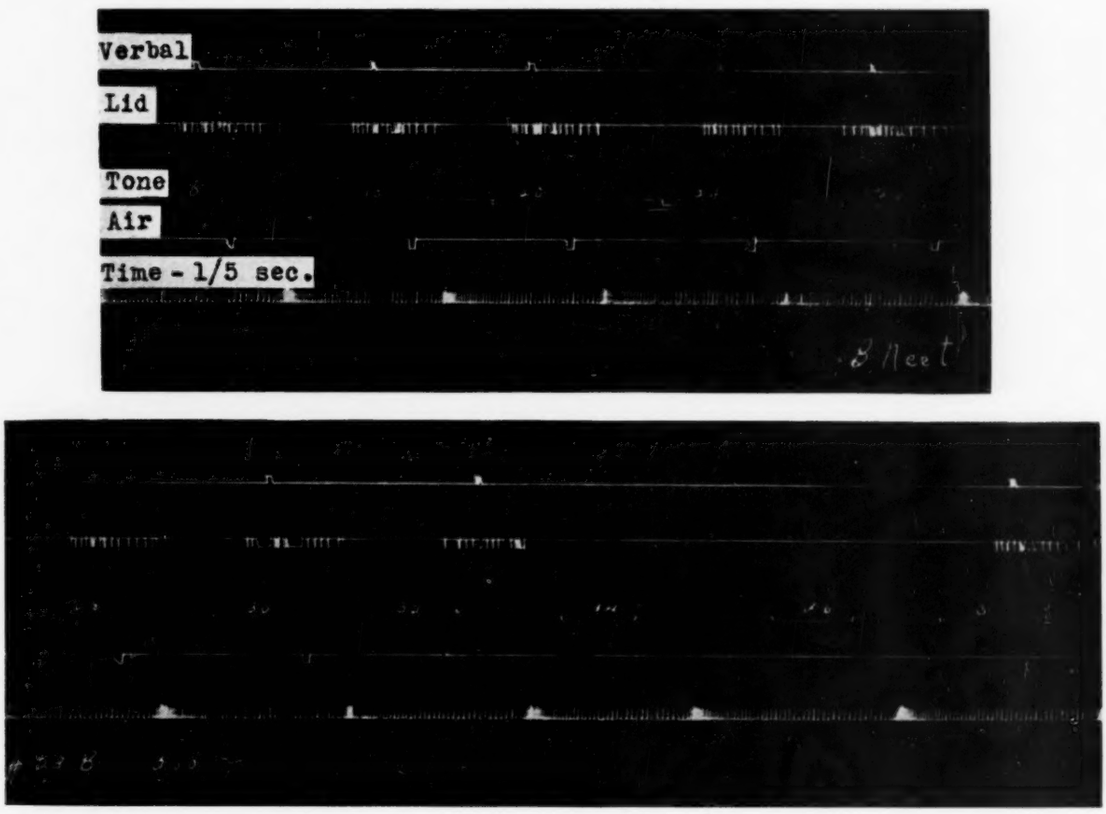

FIG. 2. Record of descending series obtained by simultaneous-response procedure (Subject B.N.).

thresholds were determined first by the manual method. The conditioned respiratory-gasp thresholds were determined during consecutive daily sittings when each subject was half way through his total number of verbal-manual sittings. These conditioned thresholds were thus determined at the approximate midpoint of the subject's practice in threshold determinations. Since the verbal and manual threshold values are an average of all determinations, practice effects would not affect one method of report more than the others, and comparisons of thresholds determined by the three modes of response are thus justifiable.

Three subjects, two of whom had been used in the previous tests, were used in the simultaneous-response procedure which involved a verbal report and a conditioned eyelid response to each stimulus presentation. After a subject's lid response had been

conditioned to the stimulating tone of 500 cycles in preliminary sittings, he was instructed to report 'yes' into a voice key whenever he heard the tone. These two responses, therefore, were made whenever the supraliminal tone was presented and were used to determine verbal and conditioned lid thresholds simultaneously.

Threshold Determinations.—All thresholds were determined by a modified method of limits, the experimenter presenting a descending and then an ascending series of tone intensities. In order to avoid the possibility of the subject's counting the number of steps in a descending series and thereby guessing at the threshold in the case of the verbal or manual methods of response, descending series of three different lengths were used. A definite order of lengths was devised so that the same number of long, medium, and short series could be used, thus equating the series for the different methods of report. The intensity step intervals were as follows: (1) long descending series: 5, 5, 2, 2, 1, 1, 1, threshold, control (see below), reinforcement; (2) medium: 5, 2, 2, 1, 1, 1, threshold, reinforcement; (3) short: 5, 2, 1, 1, 1, threshold, reinforcement. Since it was impossible for the subject to know how many subliminal stimuli were given in the ascending series, guessing was eliminated, so these series were planned to contain the same number of stimulus presentations. In the simultaneous-response procedure the lengths of series were increased by one intensity step beyond the threshold value in both the ascending and descending series.

The number of series presented during a given one-hour sitting depended on the method being used. A pair of practice series, however, was presented at the beginning of each sitting. In the case of the rotation and combination procedures, eight thresholds were determined each day. In the case of the conditioned respiratory response, four thresholds were usually determined and at times, when the condition of the subject would permit, six series were presented. Four or six thresholds per day were determined by the simultaneous-response procedure. The subjects were always given a five-minute rest period at the mid-point of each sitting.

Controls were frequently given at the end of a series. They were presented, temporally, between the threshold stimulus and the reinforcement, and consisted of a manipulation of the switches in the usual manner, with the intensity setting at minimum (far below any average threshold). They showed that the subjects were responding definitely to the tone rather than to any artifact produced by the apparatus. Whenever the subject reported 'doubtful' a stimulus of the same intensity was repeated. 'Doubtful' reports were very rare.

IV. Results

Results of Rotation Procedure.—The results of the rotation procedure are summarized in Table 1. The threshold values were calculated in terms of the audiometer intensity scale units, the maximum intensity being 40 and the minimum 1. Reliabilities were calculated in terms of the same units. The number of thresholds determined by the manual and verbal methods ranged from 199 to 300. The number differed for different subjects. In the case of the conditioned respiratory-response thresholds the number was 36 for subject C.N. and 37 for the other subjects.

From Table 1 it can be seen that regardless of the order of presentation, and in the case of each subject except B.N., the verbal report yields the lowest threshold. The manual method is the most sensitive in the case of B.N., being 0.11 points more sensitive than the verbal. In four cases the manual response ranks next to verbal, the two inconsistencies being for Hut and B.N.; the conditioning method is second to

TABLE 1

RESULTS OF ROTATION PROCEDURE

Thresholds are expressed in terms of Seashore Audiometer scale units. The letters CM, MV, and CV refer to the conditioned-manual, manual-verbal, and conditioned-verbal comparisons respectively.

	Subject	Conditioned	Manual	Verbal	Subject	Conditioned	Manual	Verbal
Presentation Order		1st	2nd	3rd		2nd	3rd	1st
Range		16–26	11–31	10–29		15–26	11–22	10–26
Number		37	214	217		37	240	300
Mean Threshold	Clk	21.97	19.85	17.96	B.N.	20.54	18.48	18.59
$\sigma_{dis.}$		1.97	4.48	4.06		2.44	2.24	3.56
$\sigma_{av.}$		.32	.31	.28		.40	.14	.21
$\sigma_{diff.}$		CM .45	MV .43	CV .43		CM .43	MV .25	CV .45
Critical Ratio		CM 4.77	MV 4.57	CV 9.42		CM 4.84	MV .44	CV 4.33
Presentation Order		2nd	3rd	1st		3rd	1st	2nd
Range			16–26	13–31		14–25	12–25	10–28
Number			216	199		36	277	300
Mean Threshold	Har*		20.60	19.59	C.N.	18.97	18.40	17.55
$\sigma_{dis.}$			2.31	3.50		2.93	2.60	4.37
$\sigma_{av.}$			.16	.25		.49	.16	.25
$\sigma_{diff.}$			MV .29			CM .51	MV .30	CV .55
Critical Ratio			MV 3.45			CM 1.11	MV 2.94	CV 2.59
Presentation Order		1st	3rd	2nd		3rd	1st	2nd
Range		16–26	16–32	15–29			12–24	9–27
Number		37	200	216			213	216
Mean Threshold	Hut	21.05	21.67	20.80	Roh†		16.26	15.35
$\sigma_{dis.}$		2.06	2.74	2.20			2.26	3.12
$\sigma_{av.}$		.34	.19	.15			.16	.21
$\sigma_{diff.}$		CM .39	MV .25	CV .37			MV .26	
Critical Ratio		CM 1.58	MV 3.55	CV .68			MV 3.46	

* No reliable conditioning was established during eight sittings in which 212 tone-shock stimulations were presented.

† This subject would not submit to the shocking required by the conditioned reflex response.

verbal in the case of Hut, and the verbal second to manual in the case of B.N. The conditioned reflex method yields the highest threshold, except for Hut, in which case the manual discrimination method is least sensitive.

The variability of the verbal method was greater than that of the other methods in four cases. In the two exceptions, Clk and Hut, the manual results were the most variable and the conditioned reflex the least variable. The manual results were least variable in four of the six cases.

From the table it can be seen that the critical ratios are high except in the cases of Hut, where the ratio is low (0.68) between the conditioned reflex and the verbal methods, and B.N., where the ratio is low (0.44) between the verbal and manual methods. The actual differences in the mean thresholds determined by the various methods are presented in Table 4, page 413. The more sensitive method is indicated by the letter after the number. The differences range in the rotation procedure from 0.11 to 4.01 in terms of Audiometer scale units.

On the basis of the results of the rotation procedure the order of sensitivity of the three forms of response compared is: verbal report, most sensitive, manual response, next, and conditioned respiratory gasp least sensitive. The order of variabilities of the thresholds by the different types of response is: verbal, most variable, manual response, next, and conditioned gasp, least variable.

Results of Combination Procedure.—Six subjects were tested by the combination procedure, three of whom had been used in the rotation procedure. The determinations of two subjects were made with the Seashore Audiometer, while those of the four others were made with the Beat Frequency Oscillator.

Table 2 presents the results of the combination method for the six subjects. The number of thresholds determined by the manual and verbal methods ranged from 80 to 96, the number differing for the various subjects. The number of conditioned-response thresholds varied from 32 to 50. The actual differences between the average thresholds are pre-

TABLE 2

RESULTS OF COMBINATION PROCEDURE

Thresholds for Car and Clk are expressed in terms of Seashore Audiometer scale units, lower values of which indicate greater sensitivity; thresholds for all others are expressed in terms of decibels of attenuation, higher values of which indicate greater sensitivity.

	Subject	Conditioned	Manual	Verbal	Subject	Conditioned	Manual	Verbal
Range		10–36	8–36	16–38		28–42	22–42	22–42
Number		32	80	80		50	88	88
Mean Threshold		25.63	26.68	28.03		33.52	32.23	34.59
$\sigma_{dis.}$	Bat	6.12	6.03	5.65	B.N.	3.01	4.29	4.37
$\sigma_{av.}$		1.08	.67	.63		.43	.46	.47
$\sigma_{diff.}$		CM 1.28	MV .92	CV 1.25		CM .63	MV .65	CV .63
Critical Ratio		CM .82	MV 1.46	CV 1.92		CM 2.07	MV 3.62	CV 1.70
Range		20–26	20–30	20–31		24–46	28–44	30–46
Number		41	96	96		50	88	88
Mean Threshold		22.63	24.12	24.27		33.20	35.64	36.89
$\sigma_{dis.}$	Car*	1.76	2.25	2.33	C.N.	4.49	4.36	4.22
$\sigma_{av.}$		.28	.23	.24		.64	.46	.45
$\sigma_{diff.}$		CM .36	MV .33	CV .36		CM .79	MV .65	CV .78
Critical Ratio		CM 4.11	MV .47	CV 4.49		CM 3.09	MV 1.93	CV 4.74
Range		16–26	15–25	15–25		26–40	16–38	20–44
Number		37	80	80		40	80	80
Mean Threshold		21.97	19.09	18.04		33.60	28.70	31.15
$\sigma_{dis.}$	Clk	1.97	2.15	2.08	Rng	3.33	4.74	4.96
$\sigma_{av.}$		.32	.24	.23		.53	.53	.55
$\sigma_{diff.}$		CM .40	MV .33	CV .40		CM .75	MV .77	CV .77
Critical Ratio		CM 7.15	MV 3.16	CV 9.91		CM 6.56	MV 3.20	CV 3.20

* Thresholds for the conditioned reflex response were obtained after all of those for the other two methods were secured. (Conditioned-response thresholds for all other subjects were obtained in a period between the first and last halves of the manual-verbal combination sittings.)

sented in Table 4, sections *B* and *C*, page 413. They range from 0.16 to 3.93 Audiometer scale units, and from 1.05 to 4.90 decibels of attenuation. The lower threshold values are indicated by the letter following each number.

The verbal response of four of six subjects yields the lowest threshold, and in the case of three of these the manual response yields the next lowest threshold. In one other case also, Car, where the conditioned respiratory response yielded the lowest threshold, the manual method ranks second in sensitivity. In no case does the manual response give the

lowest threshold; the conditioned reflex thresholds of two of the six subjects are lowest. Differences between mean thresholds of the three methods are reliable in every case except two. The threshold results of Clk and C.N. substantiate their results in the preceding section; *i.e.*, verbal response is most sensitive, manual is next, and conditioned reflex response is the least sensitive. B.N.'s order of sensitivity is different, verbal response being most sensitive, conditioned reflex next, and manual least.

The variability of the conditioned reflex method is lower than the variabilities of the verbal and manual responses in four of six subjects as shown by the standard deviation of the individual thresholds comprising the conditioned reflex mean threshold. The conditioned response is the most variable in the other two subjects. The variability of the verbal response results is greatest in the cases of three of six subjects. The manual response results are the most variable for only one subject.

Results of Simultaneous Procedure.—The results of this procedure, obtained from only three subjects, are presented in Table 3. The conditioned eyelid and the verbal thresholds coincide in practically every case. The differences between the two methods in decibels of attenuation are: Bur 0.04 (critical ratio = 0.049), Car 0.05 (critical ratio = 0.062), and B.N. 0.32 (critical ratio = 0.613). In the case of B.N. only is the difference appreciable, and in no case is the difference reliable. Table 3 also indicates the per cent of the pairs of threshold determinations which were not equal. These percentages for Bur, Car, and B.N. are respectively 8, 6.66, and 9. With subject B.N. an additional check series was presented by the simultaneous method approximately three weeks after the completion of the regular trials. It can be seen from Table 3 that the verbal report and the lid reflex yielded nearly identical thresholds at this time also.

The results of the simultaneous-response procedure show that the sensitivity of the eyelid response is not reliably greater than that of the verbal in any of the three subjects. However, it should be noted that the lid response is consistently slightly

TABLE 3

RESULTS OF SIMULTANEOUS-RESPONSE PROCEDURE

Thresholds are expressed in terms of decibels of attenuation, higher values of which indicate greater sensitivity.

	Subject	Lid	Lid-Verbal Diff.	Verbal	Subject	Lid	Lid-Verbal Diff.	Verbal
Range	Bur	24–42		24–42	B.N.	20–42		20–42
Number		50		50		100		100
Mean Threshold		33.72		33.68		31.76		31.44
$\sigma_{dis.}$		4.14		4.11		3.62		3.76
$\sigma_{av.}$		.59		.58		.36		.38
$\sigma_{diff.}$			.83				.52	
Critical Ratio			.05				.61	
		Lid and Verbal differed in 8% of the 50 thresholds (lid threshold lower in 3 cases and verbal in 1 case).				Lid and Verbal differed in 9% of the 100 thresholds (lid threshold lower in 9 cases).		
Range	Car	18–42		18–42	B.N. Check Series	30–46		30–44
Number		75		75		20		20
Mean Threshold		32.80		32.75		36.60		36.60
$\sigma_{dis.}$		4.90		4.91		4.10		3.85
$\sigma_{av.}$		.57		.57		.92		.86
$\sigma_{diff.}$			.80				1.26	
Critical Ratio			.06				0.00	
		Lid and Verbal differed in 6.7% of the 75 thresholds (lid threshold lower in 3 cases and verbal in 2 cases).				Lid and Verbal differed in 10% of the 20 thresholds (lid threshold lower in 1 case and verbal in 1 case).		

more sensitive than the verbal response. The differences between the thresholds of the two forms of response are very small (see section *D* of Table 4) and approach reliability in the case of B.N. only; this reliability amounts to only 73 chances in 100 that the true difference is actually greater than zero. In an additional check series of 20 thresholds given B.N. the two methods yielded exactly the same average threshold. The only justifiable conclusion, therefore, is that the two forms of response yielded equivalent thresholds and that they are equally sensitive modes of response.

Since the verbal and lid thresholds of this procedure were so nearly identical, it seemed advisable to carry out several controls to determine whether or not the verbal and conditioned eyelid responses were both independently controlled

by the stimulating tone. Figure 2 shows that the beginning of B.N.'s lid response preceded her verbal report of the stimulation by approximately 3/5 to 1 sec. Since this was invariably the case, it was necessary to determine whether or not the conditioned lid response was serving to arouse the verbal report.

The following controls were given: (1) the subject was instructed to say 'no' instead of 'yes' whenever she heard the stimulus tone; (2) extraneous unconditioned stimuli (puffs of air) projected on the subject's cornea evoked the reflex wink, but had no effect on the verbal response; (3) puffs of air projected on the cornea just as the tone was given in descending series caused the lid to respond but always inhibited the verbal report; and (4) light stimuli presented just prior to the tone in descending series elicited a lid response which was followed by the usual conditioned lid response to the tone and this in turn was followed by the verbal report. These controls yielded no evidence to indicate a tendency of the lid to elicit the verbal report of subject B.N. Subject Bur was given a series of controls which were somewhat similar to those given B.N. They also failed to show an interdependence of the lid and verbal responses. Subject Car was not tested with controls.

V. Discussion

From Tables 4 and 5, which present brief summaries of the major results of the investigation, the following trends can be seen:

1. *Rotation Procedure.*—The thresholds determined by the verbal report are lower than those obtained by the manual, and these in turn are lower than the conditioned-respiratory thresholds in three of four cases.

2. *Combination Procedure.*—The verbal response thresholds are lower than the manual and the conditioned-reflex thresholds. But in comparing the manual and conditioned gasp thresholds it is seen that out of six cases there are three in which the manual response is the more sensitive. In other words, this method yields no evidence to indicate that the

TABLE 4

DIFFERENCES IN AVERAGE THRESHOLDS DETERMINED BY THE FOUR METHODS OF RESPONSE

The letter after each number indicates the method of response which is the more sensitive. For example, 2.12 M in the first column means that the manual method was 2.12 audiometer scale units more sensitive than the conditioned response.

	Diff. between C and M	Critical Ratio CM	Diff. between M and V	Critical Ratio MV	Diff. between C and V	Critical Ratio CV
A. Rotation (in terms of audiometer scale units)						
Clk	2.12 M	4.77	1.89 V	4.57	4.01 V	9.42
Har			1.01 V	3.45		
Hut	.62 C	1.58	.87 V	3.55	.25 V	.68
B.N.	2.06 M	4.84	.11 M	.44	1.95 V	4.33
C.N.	.57 M	1.11	.85 V	2.94	1.42 V	2.59
Roh			.91 V	3.46		
B. Combination (in terms of audiometer scale units)						
Car	1.49 C	4.11	.15 M	.47	1.64 C	4.49
Clk	2.88 M	7.15	1.05 V	3.16	3.93 V	9.91
C. Combination (in terms of decibels of attenuation)						
Bat	1.05 M	.82	1.35 V	1.46	2.40 V	1.92
B.N.	1.29 C	2.07	2.36 V	3.62	1.07 V	1.70
C.N.	2.44 M	3.10	1.25 V	1.93	3.69 V	4.74
Rng	4.90 C	6.56	2.45 V	3.20	2.45 C	3.20
D. Simultaneous (in terms of decibels of attenuation)						
Bur					.04 C	.05
Car					.05 C	.06
B.N.					.32 C	.61

manual response is a more sensitive mechanism than is the conditioned reflex method. There is thus a discrepancy between the manual-conditioning comparison of the rotation and combination procedures; in the former the manual yielded the lower threshold.

3. *Variabilities.*—The standard deviations in Tables 1 and 2 (rotation and combination procedures) show that the conditioned respiratory-gasp response is less variable than the manual and verbal responses which are approximately equal in this respect. With the simultaneous-response procedure the variabilities of the conditioned lid response and the verbal report are essentially equal to each other, but greater than the variability of conditioned respiratory-gasp response of the rotation and combination procedures.

TABLE 5

COMPARATIVE SENSITIVITIES OF THE DIFFERENT METHODS OF RESPONSE

The numbers are the totals (for all subjects) of threshold differences in which one response is more sensitive than another. The results of Har and Roh are omitted from these comparisons because they did not participate in the conditioning.

	No. of Cases
Rotation and Combination (audiometer scale units)	
V is more sensitive than M by 4.66	4
M is more sensitive than V by .27	2
V is more sensitive than C by 11.56	5
C is more sensitive than V by 1.64	1
M is more sensitive than C by 7.63	4
C is more sensitive than M by 2.10	2
Combination (oscillator—decibels of attenuation)	
V is more sensitive than M by 7.41	4
V is more sensitive than C by 7.16	3
C is more sensitive than V by 2.45	1
M is more sensitive than C by 3.49	2
C is more sensitive than M by 6.19	2
Simultaneous (oscillator—decibels of attenuation)	
Lid is more sensitive than V by .41	3

4. *Simultaneous-response Procedure.*—The evidence tends to indicate that the conditioned eyelid response and the verbal report are equally sensitive indicators of auditory intensity stimulation.

With this summary in view, one can see that the verbal report and the conditioned eyelid response seem to be more sensitive forms of report than the manual discrimination or the conditioned respiratory gasp whose sensitivities seem to be approximately equal. These results indicate, therefore, that conditioned-reflex thresholds may be just as low as so-called 'voluntary' thresholds. This is in keeping with the results of Newhall and Sears (**5**), and with what would be expected when one considers what we know of 'voluntary' behavior. In discussing the nature of voluntary action, Hunter and Hudgins (**4**, p. 201) say that "the suggestion . . . is clearly that voluntary action is not only conditioned action, but action under the control of the self-excited receptors." The results also indicate that even though the

status of the given response, *i.e.*, conditioned or 'voluntary' has no effect on the threshold level, different response mechanisms do exhibit different sensitivities. This is in harmony with the results obtained by Brown (1) and Silverman and Baker (6) and is indicated by the evidence showing that with most subjects conditioned eyelid and verbal forms of report yielded lower thresholds than either the manual or the conditioned respiratory gasp.

Since the verbal and conditioned eyelid forms of report seem to be more sensitive response mechanisms to sensory stimulation than the other forms investigated, the question naturally arises as to why this should be so. A possible explanation might be in terms of the amount of practice to which the verbal mechanism is subjected, in terms of some sort of 'set' which might facilitate these responses or in terms of the simplicity of the responses.

VI. Summary and Conclusions

Comparisons of the sensitivities of different response mechanisms to auditory stimulation, and a comparison of the sensitivities of conditioned-response types of report with 'voluntary' modes of response have been made by comparing the absolute auditory intensity thresholds determined by (1) a verbal report, (2) a manual response, (3) a conditioned respiratory gasp, and (4) a conditioned eyelid response in ten subjects. The following results were obtained:

1. The verbal report yielded lower thresholds than either the manual or the conditioned respiratory response.

2. The manual response and the conditioned respiratory response yielded approximately equivalent thresholds. However, the evidence was not entirely conclusive. There were indications that the manual response might be a more sensitive form of report than the conditioned respiratory gasp.

3. Thresholds determined by the verbal report and the conditioned eyelid response were equivalent.

These results lead to the following conclusions:

1. The nature of a given response mechanism, either voluntary or conditioned, need not alter the threshold value

of an auditory stimulus. This is in harmony with the work of other recent investigators who have maintained that thresholds determined by these two methods are substantially equivalent.

2. Different response mechanisms differ in their sensitivity to auditory stimulation. The differences in sensitivity may be due to differences in amount of practice to which the mechanisms have been subjected, to some sort of 'set' which might facilitate one response and not another, or to differences in complexity of the musculature involved.

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THE EFFECT ON TACTUAL LOCALIZATION OF MOVEMENT DURING STIMULATION

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I. The Problem

The purpose of the present investigation was to continue the experimental study of 'The effect on tactual localization of movement during stimulation,' begun by W. S. Hulin.[1] In this case longitudinal to-and-fro movements of the arm were used in place of the transverse in-and-out movements used by Hulin. Several workers in the field have suggested that localization of tactual stimulation is correlated with reflexive movements in response to the stimulation. If such were the case, the introduction during stimulation of an arbitrary movement to cut across such a response should have some effect on the constant error of localization. It was the purpose of the present study to see if such an effect were discernible.

II. Historical

(1) Theories and observations of response tendencies in tactual localization.

William James[2] formulated a theory regarding the means by which a single stimulated spot can 'suggest its position.' He said that experience develops a habit of tracing or making lines from one cutaneous spot to another. Such habitual tracing occurs on some parts of the body, but not on others. No tracing is practiced on the back or on the stomach, and localization in these regions is vague. In the other case the precise localization which takes place in the extremities and the mobile parts results from the 'tendency, when a part of lesser discriminative sensibility is touched, to move the member so that the touching organ glides along it to the place where sensibility is greatest.' When the hand comes into contact with an object, the hand moves along until the finger tips can explore the touching object. "There thus arise lines of habitual passage from all points of a member to its sensitive tip. These are the lines most readily recalled when any point is touched, and their recall is identical with the consciousness of the distance of the touched point from the 'tip.'"

[1] W. S. Hulin, The effect on tactual localization of movement during stimulation, J. Exper. Psychol., 1935, **18**, 97–105.

[2] W. James, *Principles of Psychology*, 1890, II, 160 f.

Carr [3] likewise emphasizes the role played by response in localization. "In the process of mental development," he asserts, "a person first associates an overt localization response with each local sign. As these associations become firmly established with use, the localization of an object . . . can be appreciated as a meaning without the necessity of responding in an overt manner." For Carr local signs do not bear the dualistic connotations of many of the earlier workers, but are considered as 'differential aspects of the stimulus that correspond to the various locations of the object.'

In his article 'Local signs as orientation tendencies,' Peterson [4] carries the problem a step farther towards definiteness and objectivity. He begins with a purely random impulse of an organism in response to stimulation of some mobile part and explains how an 'orientation response' becomes established. He uses for illustration an organism in which no preferential pathways of discharge have been established. Stimulating such an organism with a pressure point upon some mobile part will send sensory impulses into the central nervous system and they will find outlet over any motor path, resulting in random movements of any mobile parts. If the stimulation is continued, the random movements will persist until the part being stimulated happens to respond. It is only at this point that any change occurs in the stimulation which will increase or cease depending upon the direction of the part's response. Since the responses of all the other extremities had no effect upon a change in stimulation, and since a response of the part being stimulated always accompanies a change, all but the latter response will gradually disappear. This is due to the fact that "sensory impulses tend to become directed into the motor channels that are active when they occur," and in addition "proprioceptive impulses involved in the relevant movements will likewise, and on the same principle, become organized into the same habit complex." This mechanism underlies the development of all of our 'orientation tendencies,' and localization habits according to Peterson.

E. B. Holt [5] offers an explanation of the development of tactual localization in terms of *Bok's* 'reflex-circle' principle. This principle is described by Holt as follows: "Let us consider *any* muscle *at a moment when* a nervous excitation, seeking some outlet of least resistance, purely fortuitously finds its way into the motor neurone of the muscle. The muscle contracts—a random movement. But now something happens which is *not* random. Every muscle has sensory organs embedded within it, its proprioceptors, which are stimulated, probably by mechanical pressure, when the muscle contracts. And so the sensory cells of this muscle (of its tendons also and of the joints involved) are now stimulated and send an excitation along their afferent nerves to the central nervous system. But this excitation arrives only a second or two after the above-mentioned random impulse has found, or while it is still finding, outlet from the central nervous system into the muscle. Therefore by Pavlov's law (or equally by the law of neurobiotaxis) the incoming excitation will find outlet along the tract just used by the random impulses, that is, will go back to, and will further contract, the very muscle from which it came. . . . Now in course of time what has happened to this (*any*) muscle, will happen to all the muscles: fortuitous impulses will sooner or later reach them all, and in all of them such a reflex-circle will then be established. The result is that in every muscle a contraction tends to re-enforce and to perpetuate itself. . . ." The consequence of this physiological characteristic of reflex responses is that they are 'adient,' that is, they 'go out to meet the stimulus, get more of it, repeat or reproduce the stimulation.'

[3] H. A. Carr, *Psychology*, 1925, *cf.* 142 f.

[4] J. Peterson, Local signs as orientation tendencies, *Psychol. Rev.*, 1926, **33**, 218–236.

[5] E. B. Holt, *Animal Drive and the Learning Process*, 1930, 37–43.

Holt applies the 'adient' character of reflex-circles to discrimination of tactual space perception. He describes, for example, the space perception on the arm.[6] A random muscular contraction will cause the arm to be brought into contact with objects in the environment causing stimulation of the tactual surfaces. For a given movement there will be a front aspect of the limb which most often is stimulated, and a 'front profile' which receives the hardest impact. Working away from the profile to either side the stimulation will be progressively less intense. The actual response to stimulation of an area of skin surface will be a summation of all the innervations of varying strengths, and will be in the direction of the stimulus because the tendencies to move obliquely to either side of the 'front profile' cancel each other. This constitutes the 'education of the skin surfaces' according to Holt. Several factors are instrumental in causing the disparity in the education of the different areas. The more distal points of the limbs are more motile, receiving more frequent stimulation and thus more 'practice.' Also the more distally located points have more momentum and strike with a greater impact giving a stronger afferent impulse. This accounts for the greater accuracy of localization of these points. Infrequency of stimulation accounts for the lagging of the education of the skin surfaces for movements of the limb along the line of its own axis, since these movements are anatomically more difficult and less frequent than transverse movements.

Evidence in support of a close relation between the sensory and the motor aspects of tactual localization has been furnished by several investigators. Krohn [7] studied an individual whose left fore-arm had been held motionless in a cast for a period of three months. After the arm was removed from the cast, Krohn found that the sensitivity of the skin on the forearm for the two-point threshold was greatly inferior to that of the right forearm. The volar surface of the left forearm had a two-point limen of 55 mm in comparison to the 20 mm limen of the other arm. The limen on the back of the injured member was 75 mm in comparison to the 17 mm limen of the unhurt arm. "It would seem that the sensibility of the skin over the injured forearm was lost simply because that member was for so long a time immobile." Further evidence was introduced by Gelb and Goldstein [8] from the study of a clinical patient who was absolutely unable to localize brief tactual stimulations, and could only localize continuous stimulation by a gross movement of his whole body which was gradually restricted to the stimulated member and finally to the stimulated spot. Spaerman [9] demonstrated the influence of posture upon tactual localization, showing that there were typical errors of localization with different positions of the limbs and head.

(2) Tests of the influences of response by introduction of other movements during stimulation.

One means of determining whether a mental process depends upon, or necessarily includes, a given type of motor response is to introduce an arbitrary movement to

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[6] *Ibid.*, 73–83.

[7] W. O. Krohn, Sensation areas and movement, *Psychol. Rev.*, 1894, 1, 280 f.

[8] K. Goldstein and A. Gelb, Psychologische Analyses hirnpathologischer Fälle auf Grund von Untersuchungen Hirnverletzter. II. Über den Einfluss des vollständigen Verlustes des optischen Vorstellungsvermögens auf das taktile Erkennen, *Zsch. f. Psychol.*, 1920, **83**, 1–94.

[9] C. Spearman, Die Normaltäuschungen in der Lagewahrnehmung, *Psychol. Stud.*, 1906, 1, 388–493.

cut across the possible response in order to see if the mental process is thereby altered in any fashion. Such a test has been applied to several mental processes.

Smith [10] instructed five subjects to count continuously to three while they attempted to memorize a series of syllables—thus inhibiting any responses of the muscles of the throat, mouth and lips which might figure in verbal memory. The results showed an increase in error from 12.6 percent to 17.7 percent by the addition of counting. In interpreting these results Smith says, "While the tables show for every subject an increase of error . . . due to the introduction of counting, it still remains doubtful whether the difference can be attributed to the inhibitory effect of the counting upon the muscles, which under normal conditions would furnish the motor expression of the syllables, or to a diversion of attention caused by the introduction of a new factor." In another series of experiments involving memory of the manual alphabet, this consideration was checked. In these experiments naming was at a minimum. The subjects were shown series of characters of the manual alphabet and were asked to reproduce them with the hands, after each series was exposed for a given time. It was found that the addition of counting had no noticeable effect, which substantiates the conclusion that in the series using nonsense syllables, counting did not distract the attention, but was automatic.

Secor [11] used whistling, repeating the alphabet or a single letter to inhibit articular responses while reading. He concluded that these responses are an aid in reading, but not necessary elements.

Fernald [12] employed with varying success a number of inhibitory responses such as pressing tongue against upper gums, exhaling slowly, swallowing. These were found for the most part unsatisfactory in studying articulatory elements in imagery. However, counting, repeating a letter of the alphabet, reciting familiar verse and whistling 'proved successful to varying degrees under certain conditions and with some subjects.'

Pintner [13] tried most of the above inhibitory methods and concluded that articulatory response can still take place if the automatic repetition is too simple. He therefore chose a more complex series to be repeated while reading, *i.e.*, 13, 14, 15, 16, 13, 14, etc. From his studies he concluded that articulation during reading is a strongly established habit, but not a necessary one since with practice it can be eliminated.

Clark [14] introduced arbitrary responses of several kinds to inhibit response during 'silent thinking.' For visual response, fixation upon a swinging bob during solution of a problem likely to arouse visual imagery, was used. Observations led to the conclusion that ". . . visual sensations do not inhibit the consciousness of imagery of the same kind. . . . With some individuals, visual images are inseparably connected with either visual fixation for better concentration of attention, or with slight relevant eye movements." The verbal response used was the repetition aloud as rapidly as possible of abc, abc, etc. The experimenter concluded that "with some individuals,

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[10] T. L. Smith, On muscular memory, *Amer. J. Psychol.*, 1896, **7**, 453–490.

[11] W. B. Secor, Visual reading: a study in mental imagery, *Amer. J. Psychol.*, 1900, **11**, 225–236.

[12] M. R. Fernald, The diagnosis of mental imagery, *Psychol. Monog.*, 1912, **14**, no. 1.

[13] R. Pintner, Inner speech during silent reading, *Psychol. Rev.*, 1913, **20**, 129–153.

[14] R. S. Clark, An experimental study of silent thinking, *Arch. Psychol.*, 1922, **7**, no. 48.

verbal imagery is inseparably connected with articulatory movements, showing that their 'imagery' is in reality 'inner speech.'" To inhibit response during 'hand motor imagery' the subjects were required to move rhythmically the thumb and forefinger of each hand. The conclusion drawn from this series of observations was that "hand motor imagery with some individuals is likewise inseparably connected with incipient hand movements."

III. Procedure

In this investigation the problem of tactual localization was taken up as it is influenced by certain types of movement, and the results were checked against a series in which no movement was used. In the movement series the arm was swung in the distal-proximal direction through a fixed distance of 12 inches. One movement was a forward swing with the arm resting volar surface up, and the other movement was a backward swing. The right upper arm hung straight down with the elbow held close to the body.

The forearm rested on a felt covered board with the hand lightly grasping a handle in order to keep the arm from rotating from side to side. The board was attached by a hinge to a swinging beam in such a manner that the arm was level throughout the course of its movement, which was terminated by felt and rubber stoppers at both the forward and rearward limits of the excursion. The swinging beam was firmly suspended from the ceiling to minimize all lateral and angular motion of the arm. The observer assumed a half-standing, half-sitting position leaning against the edge of a table with the upper portion of the trunk bent slightly forward permitting the arm to swing freely through the designated distance. The palmar surface of the forearm midway between wrist and elbow was stimulated at random points by a pressure point consisting of a stiff hair. The hair was attached to an armature which extended from an electro magnet supported by an adjustable rod above and beyond the hand grip of the arm rest. This weight was counter balanced on the other end of the arm rest in such a way that the rest balanced on the hinge. Thus when the arm swung through its excursion the rest carried it and the stimulating mechanism at a constant rate through the motion. A fixed electric contact was placed so that the pressure point was actuated and the swinging arm was momentarily stimulated when it had traversed half the distance. The swinging of the stimulus along with the arm permitted the arm to be touched at only one spot by the hair during each movement. The arm was shaved and stamped with a cross section pattern with the longitudinal and transverse axes alligned with the respective axes of the arm. The pressure point was touched with ink before each stimulation enabling the experimenters to read both stimulation and localization directly from the pattern in millimeters. The blindfolded observer was given a blunt pointed wooden stylus with which, according to Weber's second method, a tactual exploration was made until the subject, satisfied that he had hit the spot stimulated, gave his judgment. The locations of the points of stimulation and localization were recorded immediately, and the distance and direction of the localization from the stimulation were recorded in mm's and in terms of the distal-proximal, radial-ulnar directions. In the no-movement series the arm rest was clamped in place at the half way point of the excursion.

Five series of tests were performed on each observer, one at each sitting. (1) Arm was stimulated as it moved in the distal direction, localization judgments were made with arm in distal position (away from the body). (2) Arm was stimulated as it moved in distal direction; it then returned to starting position (next to body) and localization judgments were made. (3) Arm was stimulated as it moved in proximal direction, localization judgments were made with arm in proximal position (next to body). (4) Arm was stimulated as it moved in proximal direction; it then returned to starting position (away from body) and localization judgments were made.

In each of the four movement series each observer gave twelve judgments. The same sixteen observers were used throughout.

(5) A fifth (standardization) series was made as a check. The arm remained motionless in a median position and was stimulated. After a slight pause to compensate for the time consumed by the movement in the other series, the localization judgments were made. This was the no-movement

TABLE I(*a*)

DISTAL MOVEMENT–DISTAL LOCALIZATION

CONSTANT ERROR (AVERAGE ERROR) IN MM

Observer	Distal	Proximal	Ulnar	Radial
A	9.36(10.13)		1.89(5.63)	
B	4.50(12.74)		10.49(12.02)	
C	8.69(10.13)			3.02(4.50)
D		15.75(15.75)	6.39(6.39)	
E	16.88(16.88)			3.02(5.27)
F	5.63(8.64)			2.61(4.14)
G	6.75(9.77)			5.99(6.75)
H	14.99(15.75)			1.23(1.49)
I	1.13(7.11)			.77(3.74)
J	5.99(8.24)			3.74(6.75)
K	12.02(17.24)			6.39(6.39)
L		18.00(18.00)		1.13(4.14)
M	19.49(19.49)			3.74(4.50)
N	5.27(8.24)		1.49(5.99)	
O	9.36(13.86)			6.39(7.11)
P		7.52(10.49)		1.49(2.25)
Avg. C.E. for group	4.92(12.65)			1.20(5.44)
σ avg.	2.35			1.43

TABLE I(*b*)

DISTAL MOVEMENT–PROXIMAL LOCALIZATION

CONSTANT ERROR (AVERAGE ERROR) IN MM

Observer	Distal	Proximal	Ulnar	Radial
A	1.49(11.25)		.00(3.74)	
B		7.11(11.61)	5.27(9.00)	
C		1.13(7.11)		1.13(4.14)
D		7.11(10.89)	5.27(5.99)	
E	7.11(10.13)		.00(4.50)	
F	3.06(7.56)		.36(1.89)	
G	6.75(10.49)			4.14(4.86)
H	13.50(14.27)		1.49(3.74)	
I	17.13(20.61)		1.13(4.14)	
J	3.38(6.39)			1.13(3.38)
K	.77(8.24)			4.86(5.63)
L		5.27(9.77)	.00(2.25)	
M	15.75(15.75)			1.89(4.86)
N		10.49(12.74)	3.02(3.74)	
O	.77(13.50)			1.49(4.50)
P	12.38(16.11)			1.49(4.50)
Avg. C.E. for group	3.19(11.65)		.26(4.33)	
σ avg.	2.07		.64	

TABLE I(*c*)

PROXIMAL MOVEMENT–PROXIMAL LOCALIZATION

CONSTANT ERROR (AVERAGE ERROR) IN MM

Observer	Distal	Proximal	Ulnar	Radial
A	5.63(10.89)		4.50(5.27)	
B	1.89(3.38)		1.13(1.13)	
C	11.25(11.25)		3.38(6.39)	
D	8.64(9.36)			1.89(3.38)
E		12.38(15.39)	.36(3.38)	
F	3.02(4.50)		.77(3.74)	
G	7.11(10.13)			4.86(4.86)
H	12.38(13.86)		3.02(3.74)	
I		5.27(7.52)		1.49(3.74)
J	5.27(7.52)			.77(5.99)
K		1.89(11.61)		2.25(5.99)
L	2.25(5.27)			3.74(3.74)
M	8.24(9.77)			.77(4.50)
N		5.63(10.13)		1.13(4.14)
O	4.50(11.25)			5.27(5.27)
P		12.74(12.74)		1.89(3.38)
Avg. C.E. for group	2.02(9.66)			.62(4.29)
σ avg.	1.86			.68

TABLE I(*d*)

PROXIMAL MOVEMENT–DISTAL LOCALIZATION

CONSTANT ERROR (AVERAGE ERROR) IN MM

Observer	Distal	Proximal	Ulnar	Radial
A	9.86(15.75)		9.00(9.00)	
B	5.27(7.52)		5.63(6.39)	
C	18.77(19.49)			3.38(6.39)
D	.77(7.52)			.77(3.74)
E	10.13(10.89)		1.13(4.14)	
F		5.99(11.25)	4.14(4.86)	
G	6.75(9.00)			5.27(5.27)
H	9.36(11.61)		.36(4.86)	
I		1.49(7.52)	.36(5.63)	
J	5.27(5.99)		2.25(5.27)	
K	5.27(9.00)			1.13(3.38)
L		3.74(9.00)	4.14(4.14)	
M	18.00(18.00)			.77(5.99)
N	4.50(6.75)		3.02(3.74)	
O	11.61(15.39)			5.99(7.52)
P		11.57(12.38)		1.13(4.14)
Avg. C.E. for group	5.17(11.06)		.72(5.28)	
σ avg.	1.79		.94	

TABLE I(*e*)

NO MOVEMENT

CONSTANT ERROR (AVERAGE ERROR) IN MM

Observer	Distal	Proximal	Ulnar	Radial
A	4.50(6.39)		5.09(5.45)	
B		.59(7.93)	.95(3.56)	
C	7.11(8.64)			2.07(3.96)
D		2.07(7.34)	6.39(6.75)	
E	7.70(9.18)		3.56(4.32)	
F	1.71(9.59)		1.89(2.25)	
G	18.00(18.00)		2.25(3.74)	
H	2.07(6.57)		.18(3.20)	
I	1.71(8.06)		1.31(5.45)	
J	1.71(7.70)		2.84(5.09)	
K	8.06(9.59)			4.50(5.27)
L		1.13(6.44)		1.61(3.96)
M	4.50(5.81)		2.07(3.20)	
N	14.09(14.75)			2.06(4.32)
O	3.96(9.59)			1.49(5.27)
P	9.59(11.07)			3.20(4.32)
Avg. C.E. for group	5.06(9.15)		.73(4.38)	
σ avg.	1.34		.73	

series. Twenty-four judgments were made by each of the 16 observers.

For each series the constant errors of localization were computed for each observer. A constant error is the average of the algebraic sum of the errors for one axis. Thus for each observer for each series there is a longitudinal and a transverse constant error. The average constant errors of the group were also computed for each series and for the total of the movement series. These are the average of the algebraic sum of the individual constant errors for each axis. Thus for each series and for all taken together there is a transverse and a longitudinal average constant error of the group.

Also in each series and for all movement series together the average of the average errors of all subjects was computed. The average error is a simple average of the gross errors of localization without respect for direction on the given axis.

The reliability figure (σ average constant error) was computed from the formula $\sigma \text{ average} = \frac{\sqrt{\frac{\Sigma D^2}{N}}}{\sqrt{N}} \cdot ^{15}$ 'D' is the difference between each individual constant error and the average constant error of the group, and 'N' is the number of cases.

Results

1. In each of the five series, that is the four movement series and the one no-movement series, most of the observers made constant errors in the distal direction.

The magnitude of the distal errors was somewhat greater for the two series in which the arm was in the distal position during localization. These results are shown in Table II.

2. In three of the four movement series the observers made a greater number of constant errors in the radial direction.

The magnitude of the radial and ulnar errors, however, showed contradictions, namely, there was a greater average radial constant error, for the distal movement-distal localization series, and for the proximal movement-proximal localiza-

[15] H. E. Garrett, *Statistics in Psychology and Education*, pp. 118–147.

TABLE II

	Number of Observers Having Error		Average Amount of Error in mm	
	Distal	Proximal	Distal	Proximal
Distal movement–distal localization	13	3	4.92	
Distal movement–proximal localization	11	5	3.19	
Proximal movement–proximal localization	11	5	2.02	
Proximal movement–distal localization	12	4	5.17	
No movement	13	3	5.06	

tion series; there was a greater average ulnar constant error for the other series. Thus the magnitude of the errors is opposite in the two directions of movement and is opposite in the two positions during localization. These results are shown in Table III.

TABLE III

	Number of Persons Having Error		Average Amount of Error in mm	
	Radial	Ulnar	Radial	Ulnar
Distal movement–distal localization	12	4	1.20	
Distal movement–proximal localization	7	6		.26
Proximal movement–proximal localization	10	6	.62	
Proximal movement–distal localization	7	9		.72
No movement	6	10		.73

3. The purpose of the no-movement series was to establish a norm for the group in order to have a basis of comparison with the movement series as a whole. The question might here be raised regarding the effects of practice, since this series was made after the completion of the others. Several workers, however, have been unable to demonstrate definite improvement with practice for this type of localization, though improvement in the two-point limen has been shown. Thus Franz [16] says "a comparison of the results on each subject which were obtained upon the first day of careful testing (the second session of the tests) with those which were obtained upon the final day, failed to show any difference in

[16] S. I. Franz, The constant error of touch localization, J. Exper. Psychol., 1916, 1, 83–98.

accuracy of localization. It is true that these tests did not extend over long periods of time, the maximum time being about one month, so that perhaps we should not expect any considerable effect from this amount of training." His results were based upon tests made upon five subjects. In the case of the lower arm twelve hundred trials were made, or 240 on each subject which would afford a greater opportunity for practice to be effective than in the present investigation in which each of the 16 subjects had 72 trials. Cole [17] summarizes his findings in this respect: "frequent references to the question of practice appear in the literature of localization. It is generally agreed that, as opposed to ordinary two-point threshold, the localization threshold does not change with practice." Holt's theory of the 'sensory education of the skin surfaces' emphasizes the role played by learning and practice in developing the ability to localize. The above findings of Franz and Cole in no way refute this theory since they cover only a relatively negligible number of stimulations when compared to the number involved in the education of the skin surfaces which begins in the embryo and continues throughout life.

Interpreted in the light of Holt's theory, a comparison of the average of the constant errors of the movement and no movement series is significant.

	Constant Error		Average Error	
			Long.	Transv.
Movement	3.83 D	.20 R	11.26	4.85
No movement	5.06 D	.73 U	9.15	4.38

The constant error measures the tendency to localize in a given direction. This study is in agreement with many other workers in demonstrating a constant distal tendency. Peterson [18] explains the phenomenon in the following words. "The illusion of displacement of a cutaneous stimulus towards the more movable parts of the bodily surface immediately

[17] L. E. Cole, The localization of tactual space, *Genet. Psychol. Monog.*, 1929, **5**, no. 5.

[18] Peterson, *op. cit.*, p. 229.

adjoining the point stimulated is just what is to be expected on the basis of the view here outlined (see above). Speaking generally we may say that wherever on the bodily surface the mobility is greatest, 'behavior units' are correspondingly large as compared with the units measured on a physical scale; or, in subjective terms, the distance between any two discriminable points feels greater than it actually is physically."

It would logically follow that arbitrary movement cutting across the response of the organism to any given stimulation, would tend to disrupt any constant tendency. It would tend to make the scatter about the average greater and consequently the tendency in a given direction smaller. Such were the findings as recorded above. The distal constant error for the movement series was smaller than that for the no-movement series. The transverse errors, both small, were in opposite directions.

Also it would be expected that the arbitrary movement cutting across the localization response would increase the gross error (or average error) which takes no account of the constant tendency. This is substantiated by the results. The average errors for both axes were larger for the movement than for the no-movement series.

Spearman [19] used a movement of 1 cm upwards to the stimulus point. He found that the constant error diminished as compared to the still localization, but the average error remained the same.

Results Summarized

1. A constant distal tendency was demonstrated for all localization series, both movement and non-movement. A majority of the subjects showed this tendency.

2. No consistent radial-ulnar tendency was demonstrated.

3. A greater constant error was shown in the no-movement series than in the movement series.

4. A smaller average error was shown in the no-movement than in the movement series.

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[19] Spearman, *op. cit.*, p. 102.

AN EXPERIMENT ON EXTRA-SENSORY PERCEPTION [1]

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Introduction

The question of extra-sensory perception has recently been experimentally investigated by J. B. Rhine [2] in a research on the naming of special cards. Rhine used a pack of 25 'Zener' cards, which consisted of five types of cards having the following symbols: circle, rectangle, plus sign, star, and wavy lines. The cards as guessed were unknown to anyone until the score was obtained. By this method the possibility of telepathy was ruled out.

Rhine's data appear to present statistical proof of an extra-sensory capacity for perception. For example, in three years of experimentation, 24,364 correct guesses were recorded out of 85,724 trials. This is a positive deviation from chance of 7,219. When the computation is made to find what the odds are against this result being explained by the chance hypothesis the answer contains 820 figures to the left of the decimal point.

The Problem

The aim of the research here reported was to ascertain if results similar to Rhine's could be obtained through a repetition of his type of experiment. The main departure in method was the use of packs of 52 playing cards instead of Zener cards, on account of the great availability of playing cards. It was possible to use the same mathematical treatment as Rhine, except that with playing cards the probability of a correct guess due to chance was one in four instead of one in five.

[1] From the Psychological Laboratory of Princeton University.

[2] Rhine, J. B., *Extra-sensory perception.* Boston: Boston Society for Psychic Research, 1934.

To insure uniformity of procedure among a large number of subjects, the following directions were mimeographed:

1. Place a pack of playing cards face down on a table, the pack of cards having been well shuffled and cut.

2. Look at the back of the top card and, while concentrating on it, see if you can tell which of the four suits it is (spades, hearts, diamonds, clubs).

3. By means of pencil and paper write down the suit (using abbreviations) you think the first card is, and then remove the card from the top of the pack *without looking at it.*

4. Repeat the procedure for the second card, which is now the top card of the pack, and so forth through the whole pack, without looking at the faces of any cards.

(As cards are taken off the top of the pack they should be placed face down in correct order on top of the previously guessed cards.)

5. When the pack has thus been gone through, turn over the pack of guessed cards and compare its order with your written list of suits, indicating clearly the correct 'hits' you made in guessing the suits.

6. After correcting your run through the 52 cards, indicate on the written sheet the number of correct hits by drawing a circle about that total number.

Also indicate on each written trial sheet whether that trial was your first, second, third, etc., at each sitting. The sittings may be numbered by Roman numerals, and the number of the trial in that sitting by ordinary numbers. Thus in the second sitting the third trial run would be II–3.

7. Please keep all written score sheets until collected.

The usual approach to a prospective subject was to inquire casually if he or she had ever experienced any telepathic or clairvoyant phenomena. This opened the topic informally, and it was interesting to note that the majority of people seemed to have preconceived beliefs in such phenomena. They would often relate incidents that had happened to them or among their near relatives. A small minority, on the other hand, were outspokenly skeptical from the beginning; many of these individuals never entered the experiment at all.

Prospective subjects were then told about Rhine's experiments at Duke University, with emphasis upon the convincingly positive results obtained there. Finally, with the aid of the mimeographed sheet of instructions, the purpose of this experiment was outlined and a certain time in the future was set for the collection of the experimental data. These data were to include *at least* two runs through the deck, in which the guessed card was indicated each time by its first letter. Out of approximately 400 people approached, only

132 became actual subjects in the experiment. Many people found themselves too busy, or procrastinated, or lost the instructions, or simply forgot completely.

It is reasonably safe to say, however, that this mortality of possible subjects did not tend to bias the results away from proof of clairvoyance, because those who were really interested and thought they might be clairvoyant were not the ones who failed to follow the procedure or save the results. On the contrary, the great mortality of potential subjects came from those openly skeptical and those dubious enough not to care, neither of which groups would have approached the experiment in a frame of mind conducive to a fair test of clairvoyance.

Results

When the results of the preliminary survey were tabulated, it was found that the 132 subjects had run through 482 decks of cards, with a grand total of 25,064 cards guessed. This gives a general average of 3.6 runs through the pack per person.

A distribution curve (Fig. 1) was made from the frequency of correct guesses in each of the 482 runs through the packs of cards. The horizontal axis represents the number of hits per 52 cards guessed, while the vertical axis shows the number of times (frequency) each occurred.

The mathematical computations give the following results:

1. The mean of the sample is 13.17,
2. The standard deviation of the sample is 2.9979,
3. The standard deviation of theoretical distribution is 3.1225,

By computation and tables[3] it was found that in 96 cases out of 100 a greater deviation under the chance hypothesis should be expected. Therefore, the deviation in the foregoing table is not significant of any acting force other than chance.

From these results it is evident that no extra-sensory cues were used by the 'average man' of the group investigated.

[3] Fisher, R. A., *Statistical methods for research workers.* London: Oliver and Boyd, 1932.

But what about the individuals? It is perfectly possible for some individuals to have been clairvoyant, and yet to have been lost statistically among the 132 lumped together.

Accordingly, for each of the 132 subjects there was calculated the average of their several runs through the deck, and these averages were then listed in order from high to low. The two extremes of the spread were thus found

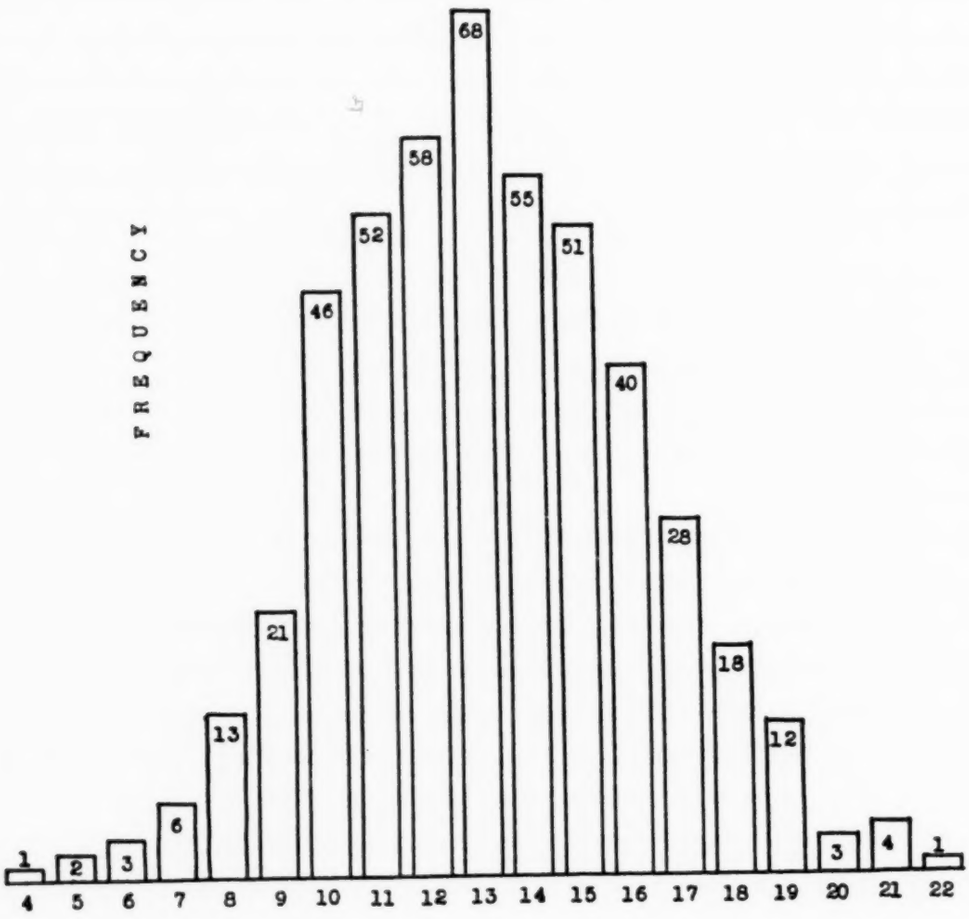

FIG. 1. Frequency of number of hits per run through the pack.

to be 17.66 and 8, chance value being 13. The median was 13 and the mode was 13. The mean was 12.88.

Among the individual variations for single runs through the deck, the following were the most unusual: F.R.M. in one run made only 4 correct hits out of 52, while S.W.Jr. got 22 in one run. (The latter also scored a 5 out of 52.) In regard to consecutive runs or misses, D.A.R. made 6 hits in succession while scoring a 19 out of 52. On the other hand,

S.G.T.Jr. missed 24 guesses in succession when scoring a 5 out of 52.

In testing further for evidence of clairvoyance among individuals, the six men who had scored the highest averages and the six men with the lowest averages (in the general survey part of the experiment) were selected for additional experimentation.

For this further testing it was deemed advisable to use the same order of cards for all 12 men, so all the men could be compared directly in their hits and in their errors. The high six and the low six could also thus be compared as groups with each other, directly and fairly.

Accordingly, 260 cards (five new, identical packs) were obtained and well shuffled. They were then cut and maintained in that order, the order being unknown to everyone, including the experimenter (thus excluding the possibility of telepathy). The twelve selected subjects then guessed this series of cards without correcting for hits. While they did the guessing the experimenter manipulated the cards, exposing the back of the top card and removing it when guessed, always being careful to maintain the proper order. (This was accomplished by placing a joker face up at the bottom of the pile, and placing each card as guessed face down beneath the joker. When the joker appeared, the run was completed.)

After making a 'master' score sheet of the cards as they actually were in the series of 260, the score sheets for the twelve men were then corrected and scored.

On inspection of Table 1 one is immediately impressed by the fact that the two former groups of high and low men did not remain separated. Top score *was* made by a man from the high group, but second and third places were usurped by men of the original low group, etc. Also, every man without exception shifted toward chance value, seven of the twelve shifting so far that their new averages reversed their position in relation to chance value.

To test whether these results were significant or not, the same formula was first applied as that used by Rhine: D./P.E.

TABLE 1

Subjects	Preliminary Survey	Further Experimentation		
	Original Average	Hits in the 260	Dev. from Chance	Avg. by 52's
Original High Men:				
Pn.	17.66	68	+ 3	13.6
Hr.	17.29	71	+ 6	14.2
Br.	17.00	69	+ 4	13.8
Cn.	17.00	54	−11	10.8
Wl.	17.00	76	+11	15.2
Ce.	17.00	66	+ 1	13.2
Original Low Men:				
Ww.	9.00	65	0	13.0
Ms.	9.00	69	+ 4	13.8
Gs.	8.33	66	+ 1	13.2
Hn.	8.00	63	− 2	12.6
En.	8.00	73	+ 8	14.6
Pr.	8.00	75	+10	15.0

TABLE 2

Subject	Dev./P.E.
Wl.	+2.336
Cn.	−2.336
Pr.	+2.123
En.	+1.699
Hr.	+1.274
Br.	+0.849
Ms.	+0.849
Pn.	+0.637
Hn.	−0.425
Gs.	+0.212
Ce.	+0.212
Ww.	0.000

In the biological sciences a significant D./P.E. is generally taken as 4 (or above), 4 giving odds of 142 to 1 under the chance hypothesis. Further increases in D./P.E. ncrease the odds at a very rapid rate.

So far the mathematical procedure used by Rhine has been exactly paralleled. Such procedure tells a great deal of the story, but not all; for it takes into account *only* the correct guesses and neglects to consider the nature of the wrong guesses.

The best way mathematically to investigate this more detailed aspect of the problem is by the Contingency Method. In this method the suit guessed is plotted against the actual

suit. There are thus 16 possibilities, according to the following figure:

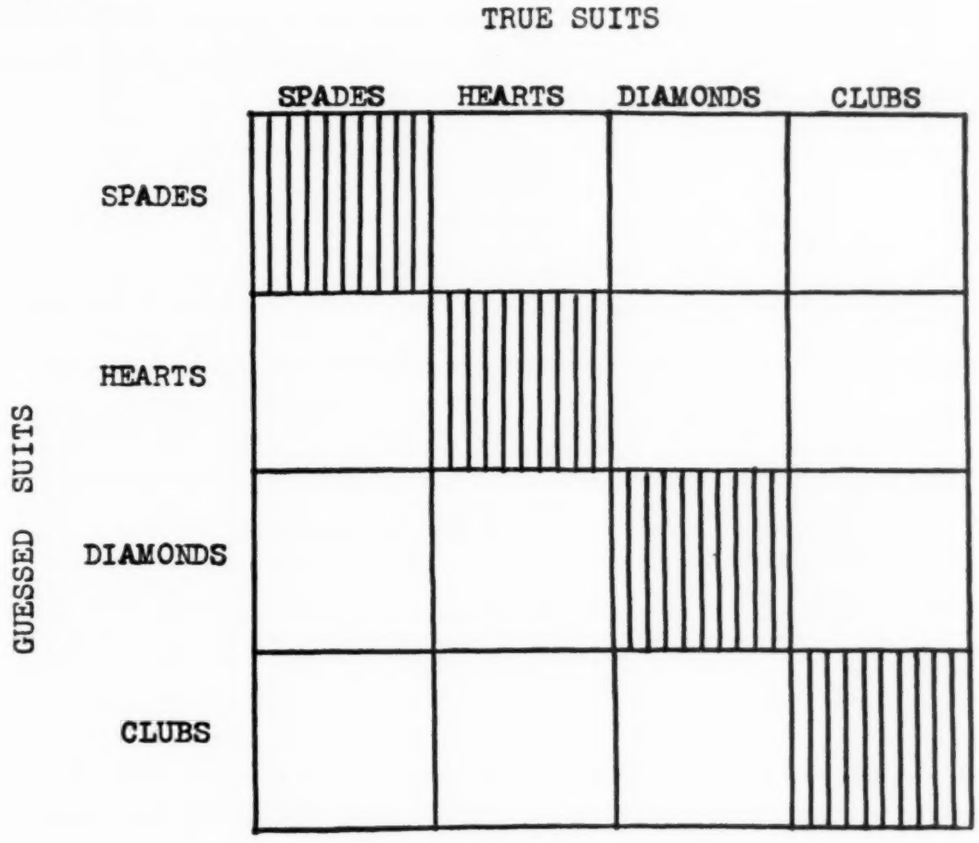

FIG. 2.

When the proper numbers have been entered in all the squares, the correct guesses fall in the diagonal from the upper left corner to the lower right corner, as shown by the shaded squares.

Rhine's method of D./P.E. takes into account *only* the shaded categories, leaving the twelve white squares neglected as individual entities by bunching them altogether. By including the white squares in the computations, the Contingency Method corrects for any tendency the subject may have for calling some suits relatively more often than others.

From the Contingency Method Equation [4] a number is obtained which, when entered in the tables published by R. A. Fisher, gives the probability of getting a result more

[4] *Op. cit.*

unfavorable to the chance hypothesis than that actually obtained.

The results of the 12 selected men as a group are shown in the following table which is a summary of the 3120 turns of cards guessed by them.

TABLE 3

TRUE SUITS

Composite Table of 12 *Men*

Chance value per square: 195. x^2 from tables: 5.64287. Therefore P from tables: .774.

		Spades	Hearts	Diamonds	Clubs	
Guessed Suits	Spades	192	188	205	192	777
	Hearts	203	216	184	193	796
	Diamonds	180	184	191	179	734
	Clubs	205	192	200	216	813
		780	780	780	780	3120

Since the total results show that in 77.4 cases out of 100 a worse distribution would have been obtained by chance alone in repeating the procedure, the results in totals are not significant of any acting force other than chance.

In passing it is interesting to note that these 12 men show a marked tendency to call clubs and hearts more often than spades and diamonds.

TABLE 4

Suit Called	n	Dev. from Chance
Clubs	813	+33
Hearts	796	+16
Spades	777	− 3
Diamonds	734	−46

The Contingency Method evaluates this tendency properly.

The Contingency Method was then applied to each of the 12 individuals, and the equation for x^2 computed for each man, with the following results:

TABLE 5

SUMMARY OF INDIVIDUAL RECORDS

Subject	Value of x^2	*P* from Tables
Wl.	17.651	.042
Pr.	12.732	.18
Br.	9.592	.39
Ms.	9.306	.42
Ce.	8.100	.52
Cn.	7.883	.55
En.	7.871	.55
Ww.	6.751	.66
Gs.	5.983	.70 to .80
Hr.	4.905	.80 to .90
Pn.	3.134	.95 to .98
Hn.	2.079	.99 to 1.00

When x^2 is 2.088, *P* is .99; when x^2 is 21.666, *P* is .01.

Since no one of these individual x^2 values when entered in the tables is significant, it follows that all these results may adequately be explained by the chance hypothesis alone. In other words, none of the six best men (nor the six worst) from the preliminary survey produced any results that cannot easily be attributed to the workings of chance alone.

Some advocates of clairvoyance may object that the distinguishing shapes representing the suits of cards are too small for extra-sensory discrimination. Therefore a special check-up was made on the guesses of the aces, which are larger than the figure on the rest of the cards, and stand alone in the center of the card. The application of the Contingency Method to these data gave a value for x^2 of 8.069. From the tables *P* is .53, which is not significant of any agent other than chance in the discrimination of aces.

CONCLUSION

In conclusion, it is evident from the above results and computations that there is no evidence of extra-sensory perception either in the "average man" of the group investigated or in any particular individual of that group. The discrepancy between these results and those obtained by Rhine are due either to uncontrolled factors in experimental procedure or to the difference in the subjects.

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VARIATION IN INTENSITIVE SENSITIVITY TO LIFTED WEIGHTS

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Problem

The purpose of the following experiments was to investigate the constancy of ability to discriminate lifted weights. Here the term constancy is used to mean *only* invariability of sensitivity to different weights. Constancy in ability to discriminate intensities is implied by Weber's law. Other investigators, particularly Hecht and Crozier, have found, in their studies with lower animals, absence of constancy of this ability. The importance of the manner of variability of sensitivity in human subjects becomes apparent in the light of their results. Possible deviations in sensitivity can be examined by use of conventional psychophysical methods. Experiments, employing these methods and using a wide range of the stimulus, were devised in order to measure sensitivity of human subjects to lifted weights.

Experimental

Preliminary Experiment

Methods and Procedures.—The problem here was to determine the acuity of discrimination under three different conditions, and to discover what differences in acuity were present under these circumstances. The subjects used were a man and a woman, students in an elementary psychology course and totally unacquainted with psychophysical experiments. In this experiment only one set of weights was used. This set had five members, ranging from 92 to 108 grams with a difference of four grams between members, and an additional weight of 100 grams which was used as the standard. These weights were manufactured so that they were alike in size and shape and differed only in mass.

In addition to the weights, the apparatus consisted of a screen between the subject and the weight, so that the weight was not visible to him, and an arm-rest which fitted the angle at the elbow when the arm rested comfortably on the table. The weights were presented at the same place every time so that the arm always remained in the same position while awaiting the presentation. Three different movements were employed for lifting the same weights, a wrist movement, an elbow movement and a shoulder movement. When the wrist movement was employed no part of the arm

above the wrist was moved; with the elbow movement, no part above the elbow was moved; with the shoulder movement, the whole arm was moved along with the movement of any of the more distal joints. By means of a metronome, the time-interval between the presentations of each member of a pair was held constant in an effort to avoid any variation of the time-error. The observations were made in periods of one hour each, with intervals of approximately one week between experimental periods.

The subjects were given the following instructions: "You will be presented with weights successively and rhythmically. You are to judge always the second in relation to the first and report your judgment as 'heavier,' 'equal' or 'lighter.' In all cases where you are doubtful, report 'equal' unless your doubt is due to some distraction, in which case you will report 'doubtful.' Please make and report judgments as quickly as possible."

The method of constant stimulus differences was the one chosen for use here. Two hundred fifty comparison judgments, with each kind of movement, were obtained from each subject. About twenty-five 'practice' judgments were taken at the beginning of each experimental period.

Results

The following tables present the results of this experiment. The crude data were put through a process of calculation called Urban's Tables, a formula for weighting properly the values of each set of observations or judgments depending upon how remote they are from the middle of the range, or the standard weight of the set.

In general, these results show that there is a decrease in the difference limen, DL, and the interval of uncertainty, I.U., as the movement in the arm becomes less distal. A

TABLE I

THE VALUES OF THE MEASURE OF PRECISION, h, THE PROBABLE ERROR OF THE DISTRIBUTION OF JUDGMENTS, P, AND THE DIFFERENCE LIMEN, DL

Obs. I

	Judgments of Heavier			Judgments of Lighter		
	h	P	DL	h	P	DL
Wrist	.0886	5.3826	105.4700	−.1042	−4.5768	95.1320
Elbow	.1193	3.9975	102.6808	−.1117	−4.2695	96.6052
Shoulder	.1137	4.1944	100.8564	−.0950	−5.0200	97.3192

Obs. II

Wrist	.0656	7.2698	96.8848	−.0791	−6.0290	95.4516
Elbow	.1015	4.6985	95.0124	−.1020	−4.6755	94.9432
Shoulder	.1038	4.5944	97.6844	−.1038	−4.5944	97.6844

TABLE II

THE VALUES OF I.U., DL AND P FOR EACH MOVEMENT AND EACH SUBJECT

Obs. I

	Wrist	Elbow	Shoulder
I.U.	10.338	6.0756	3.5372
DL.	5.1690	3.0378	1.7686
P.	9.9594	8.2670	9.2144
Obs. II			
I.U.	1.4332	.0692	0.00
DL.	.7166	.0346	0.00
P.	13.2988	9.3744	9.1888

decreased limen means increased sensitivity, when the weights remain the same. This progressive increase in sensitivity could not have been due to practice because these data were obtained from the two subjects in reversed temporal order. With the exception of the inversion of the results for one subject at the elbow and shoulder movements, a decrease in P accompanies the decrease in DL, although by no means proportionately.

A possible explanation of these results is that there are more muscle-fibers, and therefore more receptors, brought into function as the fulcrum for the movement of the arm becomes more proximal. If this hypothesis is correct, then any other method of increasing the number of functional receptors should bring about an increase in sensitivity also. In order to test the correctness of this hypothesis, experiments were planned, in which the type of movement was held constant, but the measurements were taken at various places along the scale of intensities.

Experiment I

Methods and Procedures.—The data were obtained, as in the preliminary experiment, by the method of constant stimulus differences (12). Only the wrist movement was employed and judgments were made on seven different sets of weights by each subject. There were five different weights in each set, plus a standard weight. The mass of the various weights is shown in the following table. The values appearing in the third column represent the value of the standard for that particular set, the corresponding row.

TABLE III

No. of Weight in Set	I	II	III	IV	V
Set 50.....	46	48	50	52	54
Set 100.....	92	96	100	104	108
Set 150.....	138	144	150	156	162
Set 250.....	230	240	250	260	270
Set 350.....	322	336	350	364	378
Set 450.....	414	432	450	468	486
Set 550.....	506	528	550	572	594

The weights, as in the preliminary experiment, were all of the same size, shape and material, differing only in mass. They were not visible to the subject and were always presented to him at the same place (avoiding the space error), by means of a turn-table, a disk which could be rotated and upon which the weights rested so that they could be turned around to any position. While lifting the weights, the subject always sat in a straight-backed chair and extended his right arm through an aperture in a screen.

These experiments were carried out in a darkened room in order to decrease the distraction for the subjects.[1] There was a light behind the screen only, so that the experimenter could see which weights he was presenting and record the judgments. Each member of a set was presented twenty-five times to each subject. The comparison weights were presented in haphazard order and at the beginning of each sitting each subject was put through a training period in order to establish a rhythm of lifting which kept the time-interval between standard and comparison weight relatively constant. The instructions were the same as those used in the preliminary experiment, except that here no judgments of 'equal' were to be given.

Results

The raw data from this experiment have been converted into the results presented in the following tables. Since no judgments in the intermediate category were taken in this experiment, the h-values for the 'heavier' judgments will equal the h-values for the 'lighter' judgments, except that the former will be positive while the latter are negative. For this reason Table IV presents only the h-values for 'heavier' judgments.

Comparison of h-values in Table IV shows the variability in precision between the observers and between one set of weights and another. The average h shows more clearly how

[1] The subjects used in this experiment were three men, A. J. Harris, W. A. Hunt and P. E. Huston, all graduate students in the Harvard Psychological Laboratory, and Miss J. Steinberg, a senior in Radcliffe College with psychology as her major subject. With the exception of Miss Steinberg, all of these subjects could be said to be experienced in making psychological observations. Hereafter, these subjects will be designated as Ha, Ht, Hn and St, respectively.

the factor of precision decreases as one proceeds from Set I to Set VII, from weights of approximately fifty grams to those approximating 550 grams. As the value of h gets smaller progressively from Set I to Set VII, it means that curves representing the distribution of the percentages of 'heavier' and 'lighter' judgments for each set of weights get flatter as the weight of the stimulus increases. One thing that h means, then, is the flatness or steepness of the curves. As the value of h increases, the precision of the judgments also increases. It has been shown that the value of h can change without its affecting a liminal measure in any way (**2**).

Since no judgments in the intermediate category were recorded in this experiment, the limen was not used as a measure of sensitivity. Under these conditions and with the

TABLE IV

VALUES OF h, FOR THE JUDGMENTS OF 'HEAVIER,' OBTAINED FROM THE DATA, AND THEIR AVERAGES FOR EACH SET OF WEIGHTS

	Set I	Set II	Set III	Set IV	Set V	Set VI	Set VII
Hn.....	.0857	.0731	.0670	.0507	.0532	.0301	.0218
Ht.....	.0771	.0869	.0737	.0444	.0336	.0232	.0247
St.....	.0878	.0687	.0558	.0431	.0206	.0147	.0155
Ha.....	.0562	.0508	.0504	.0320	.0136	.0195	.0133
Aver.....	.0767	.0699	.0617	.0426	.0303	.0219	.0188

use of the method of constant stimulus differences the probable error of the distribution, P, which is a measure of variability is also a better objective measure of sensitivity than the limen (**5**). It was therefore decided to adopt this measure which is derived in much the same way as the limen. To find the liminal value, the lower limen is subtracted from the upper limen to get an interval of uncertainty and this is divided by two. Here, then, the P-value for the 'lighter' judgments, P_l, is subtracted from the P-value for the 'heavier' judgments, P_h. This remainder corresponds to the interval of uncertainty and can be divided by two to get a quotient which corresponds to a limen (**5**). In Table V, below, are presented the P-values, $P_h - P_l$, derived from the data of this experiment.

TABLE V

THE P-VALUES FOR EACH OBSERVER AND EACH SET OF WEIGHTS WITH THE AVERAGES FOR EACH SET OF WEIGHTS

	Hn	Ht	St	Ha	Average
50	11.0296	12.3710	10.8634	16.9716	12.8339
100	13.0478	10.9758	13.8836	18.7756	14.1707
150	14.2358	12.9416	17.0932	18.9246	15.7988
250	18.8126	20.4820	22.1298	29.8062	22.8077
350	17.9284	28.3868	46.3010	70.1324	40.6872
450	31.6876	40.9356	64.8844	48.9128	46.6051
550	43.7522	38.6154	61.5354	71.7142	53.9043

Table V shows that the P-values increase in size as the sets of weights become heavier. This is not surprising, since one would not expect the same absolute amount of variability with vastly different sets of weights. The P-values, however, vary only about one to four while the sets of weights vary as one to eleven. In order to use the P-values as a comparative measure of sensitivity, they must be put on an equal footing. This can be done by devising a relative P-value, or dividing the P-value for each set of weights by the value of the standard weight for that set. Table VI presents

TABLE VI

THE RELATIVE P-VALUES AND THEIR AVERAGES

	Hn	Ht	St	Ha	Average
50	.2226	.2474	.2173	.3394	.2567
100	.1305	.1097	.1388	.1877	.1417
150	.0949	.0863	.1073	.1262	.1037
250	.0792	.0819	.0885	.1192	.0922
350	.0512	.0811	.1323	.2004	.1163
450	.0704	.0910	.1442	.1087	.1036
550	.0795	.0702	.1119	.1304	.0980

these relative P-values and their averages and from this table it is evident that the relative variability is not equal for all sets of weights. It is especially high for the lighter sets of weights.

The above relative P-values are analogous to relative I.U. values.

It was planned to carry out more experiments of the same general kind for three reasons: first, to obtain more grounds

for a comparison of P with I.U., as a measure of sensitivity; second, to gain more evidence on the question of the variability of sensitivity and its relation to the strength of the stimulus; third, to extend the range of stimuli beyond the limits of the weights already used to discover what happens to the sensitivity at these points.

Experiment II

Methods and Procedures.—The apparatus was approximately the same as that used in the preceding experiment, but the sets of weights were different and the experiment was conducted with a different technique, which necessitated different instructions to the observers. Again the felt-padded turn-table was used, but the sets of weights varied from a set around twenty-five grams to a set around 600 grams. The lightest set had a twenty-five gram weight for a standard and five comparison weights, one of which was also twenty-five grams, while two were heavier and two were lighter and differed by the amount of one and five-tenths grams. Thus, this set ranged from twenty-two to twenty-eight grams. A second, similar set ranged around a standard of fifty grams, but with two grams difference between the different comparison weights, thus ranging from forty-six to fifty-four grams. The four other sets of weights had standards of 150, 350, 550 and 600 grams, with differences between members of six, fourteen, twenty-two and twenty-four grams, respectively.

There were five observers in this experiment.[2] The instructions to the observers were as follows: "You will be presented with pairs of weights upon which you are to make comparison judgments, judging the second weight lifted in reference to the first weight lifted, *i.e.* as to whether it (the second) is heavier than, lighter than, or equal to the first weight. Report your judgment, 'heavier,' 'lighter' or 'equal,' as soon as possible after lifting the second weight."

As soon as one judgment was recorded, another pair of stimuli was presented. At the beginning of the experiment a metronome was used in an attempt to establish a controlled rhythm of lifting the weights, but the subjects reported that the metronome distracted their attention and made it too difficult to judge the weights. Consequently, the metronome was abandoned and it was later discovered that the lifting of the weights was rhythmical without the use of the metronome, although the rhythm was not the same for all observers. There were two sittings during each experimental period and 125 comparison judgments were taken at each sitting.

In this experiment the method of constant stimulus differences was employed. The judgments were recorded as reported, 'heavier,' 'lighter' or 'equal.' At the completion of a sufficient number of judgments upon each member of the set of weights, the percentages of the 'heavier' and 'lighter' judgments were taken separately and put through the Urban process of calculation. By this process one eventually arrives at the values for the upper and lower difference limens, DL's, and their respective h's or measures of precision. By subtracting the lower DL from the upper DL the interval of uncertainty is obtained. Half the interval of uncertainty is equivalent to the DL for the total number of judgments. This can be taken as a measure of discriminability for that particular stimulus. It has also been argued that h can serve as a measure of discriminability (10) (12).

[2] These were D. W. Chapman, J. Steinberg, D. S. Oberlin, W. Stavsky and P. M. Zoll.

From the data of this second experiment are derived the h-values for judgments of 'heavier' and of 'lighter,' the upper and lower limens, DL, and the interval of uncertainty, I.U. All of these values, in addition to the values of P, or $P_h - P_1$, are presented in the following table.

TABLE VII

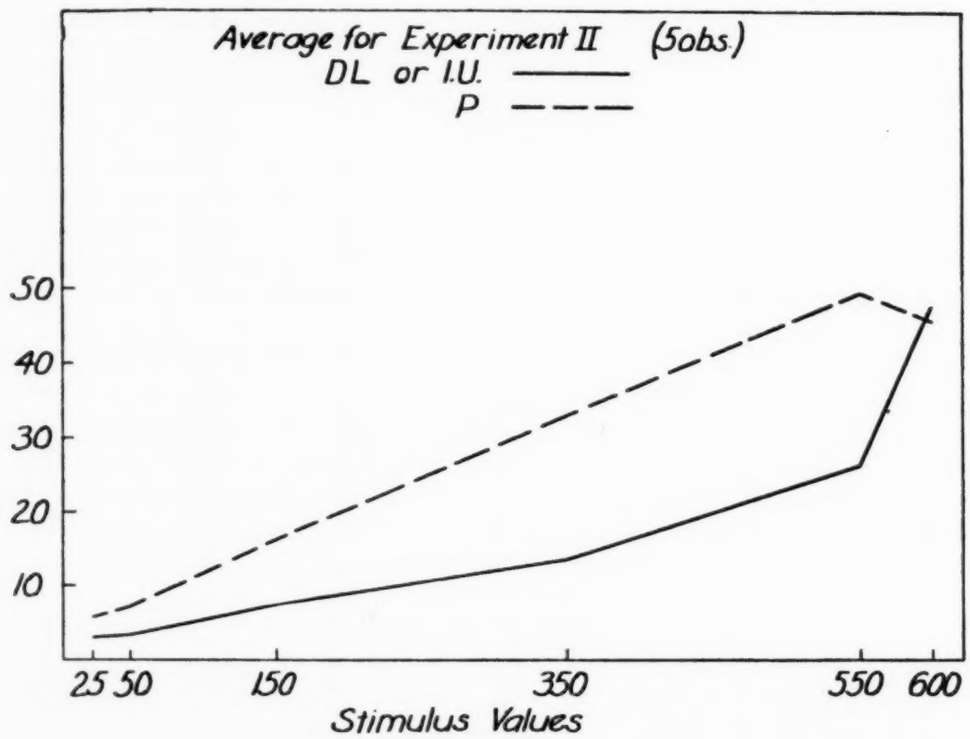
	Upper DL	Lower DL	I.U.	Upper h	Lower h	$P_h - P_1$
			J.S.			
25	25.16	23.80	1.36	.4581	.2111	3.3001
50	47.02	43.41	3.61	.1303	.1295	7.3426
150	145.01	138.10	6.91	.0571	.0630	15.9218
350	336.78	323.98	12.80	.0332	.0375	27.0818
550	557.09	519.95	37.14	.0228	.0260	39.2589
600	627.24	550.95	76.47	.0197	.0209	47.0262
			D.W.C.			
25	26.22	24.06	2.16	.2745	.2249	3.8552
50	51.55	48.48	3.07	.1469	.1624	6.1830
150	152.01	143.65	8.36	.0612	.0601	15.7276
350	348.48	333.64	14.84	.0332	.0343	28.2683
550	545.27	521.42	23.85	.0204	.0221	44.9567
600	595.21	569.14	26.07	.0221	.0214	43.8642
			D.S.O.			
25	26.18	22.90	3.28	.2075	.2004	4.6780
50	51.22	47.63	3.59	.1589	.1272	6.7505
150	151.88	141.60	10.28	.0563	.0538	17.3350
350	350.88	329.67	21.21	.0269	.0248	36.9584
550	547.18	514.74	32.44	.0169	.0177	55.1625
600	602.67	563.67	39.00	.0210	.0200	46.6632
			W.S.			
25	25.08	22.16	2.92	.1601	.1656	5.8586
50	49.41	46.45	2.96	.0961	.0961	9.9300
150	150.97	147.50	3.47	.0460	.0487	20.1600
350	344.83	337.10	7.73	.0182	.0206	49.3538
550	537.56	520.88	16.68	.0155	.0148	62.9262
			P.M.Z.			
25	26.50	21.15	5.35	.0886	.0643	12.7994
50	52.11	47.99	4.12	.1331	.1481	6.8031
150	145.53	135.44	10.09	.0708	.0649	14.0841
350	347.61	336.79	10.82	.0360	.0406	24.9935
550	543.23	522.66	20.57	.0226	.0201	44.9282

Table VIII, below, presents the averages for the above values for each set of weights.

TABLE VIII

	Upper DL	Lower DL	I.U.	Upper h	Lower h	$P_h - P_l$
25	25.83	22.81	3.01	.2378	.1733	6.0983
50	50.26	46.79	3.47	.1331	.1327	7.4018
150	149.08	141.26	7.82	.0583	.0581	16.6457
350	345.72	332.24	13.48	.0295	.0316	33.3316
550	546.07	519.93	26.14	.0196	.0201	49.4465
600	608.43	561.25	47.18	.0209	.0208	45.8512

These values of I.U. and P, plotted against the weights, are represented in Fig. 1.



The absolute limens are not presented in these tables, but they are found by dividing the interval of uncertainty by two. It is apparent, then, that the values of any limenal measure increase as the stimulus increases. However, for purposes of comparison, to show how the sensitivity or discriminability varies over the full range of weights employed, it is necessary to have relative difference limens and not absolute ones.

Relative difference limens are derived by dividing the absolute difference limens by the value of the stimulus yielding those limens. Relative intervals of uncertainty can be equally well used here; the values are twice as high as for relative difference limens but the same relations are preserved. From the same data, there are available the P-values. These are obtained by taking the probable error of the psychometric function for the 'heavier' judgments and subtracting from it the probable error of the psychometric function for the 'lighter' judgments. It is also essential that the relative P-values be dealt with rather than the absolute ones given in Tables VII and VIII, above. Table IX, following, gives

TABLE IX

VALUES OF RELATIVE I.U. AND RELATIVE P

	J.S.		D.W.C.		D.S.O.		W.S.		P.M.Z.	
	I.U.	P	I.U.	P	I.U.	P	I.U.	P	I.U.	P
25	.0544	.1320	.0864	.1542	.1312	.1871	.1168	.2343	.2140	.5120
50	.0694	.1469	.0614	.1237	.0718	.1350	.0592	.1986	.0822	.1361
150	.0521	.1061	.0557	.1049	.0685	.1156	.0231	.1344	.0673	.0939
350	.0385	.0774	.0424	.0808	.0606	.1156	.0221	.1410	.0309	.0714
550	.0475	.0714	.0434	.0817	.0590	.1003	.0303	.1144	.0374	.0817
600	.0786	.0784	.0435	.0731	.0650	.0778				

TABLE X

VALUES OF RELATIVE I.U. AND RELATIVE P, AVERAGED FOR ALL SUBJECTS

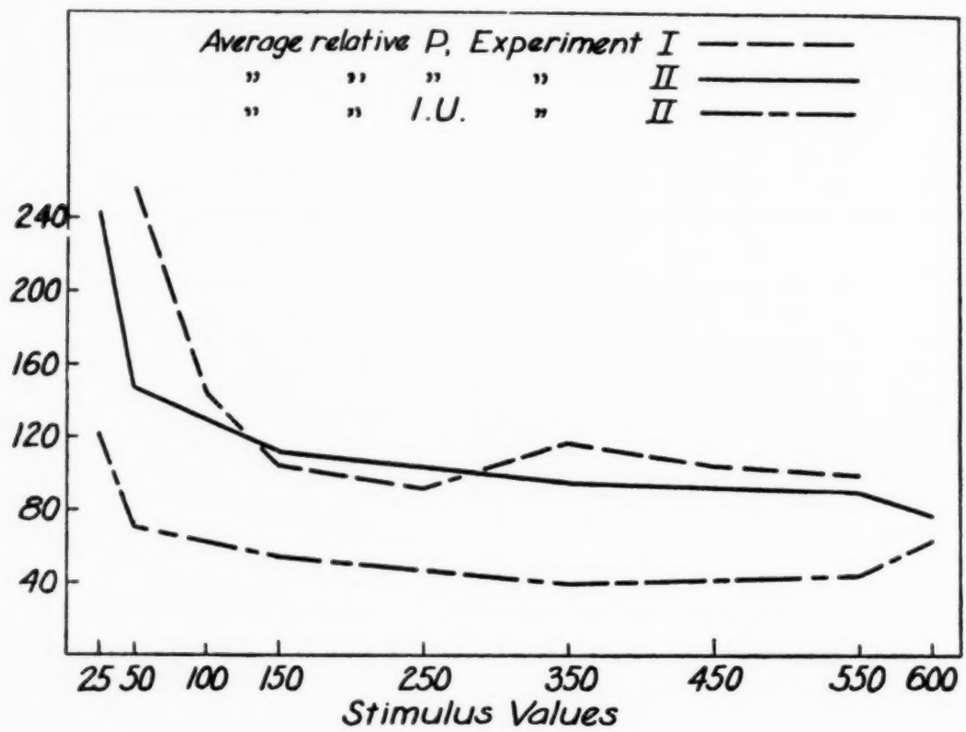
	Average Relative I.U. Values	Average Relative P-values
25	.1206	.2439
50	.0688	.1481
150	.0533	.1110
350	.0389	.0952
550	.0435	.0899
600	.0624	.0764

the values for the relative intervals of uncertainty and the relative P-values for all subjects and for each level of the stimulus used in the second experiment.

DISCUSSION

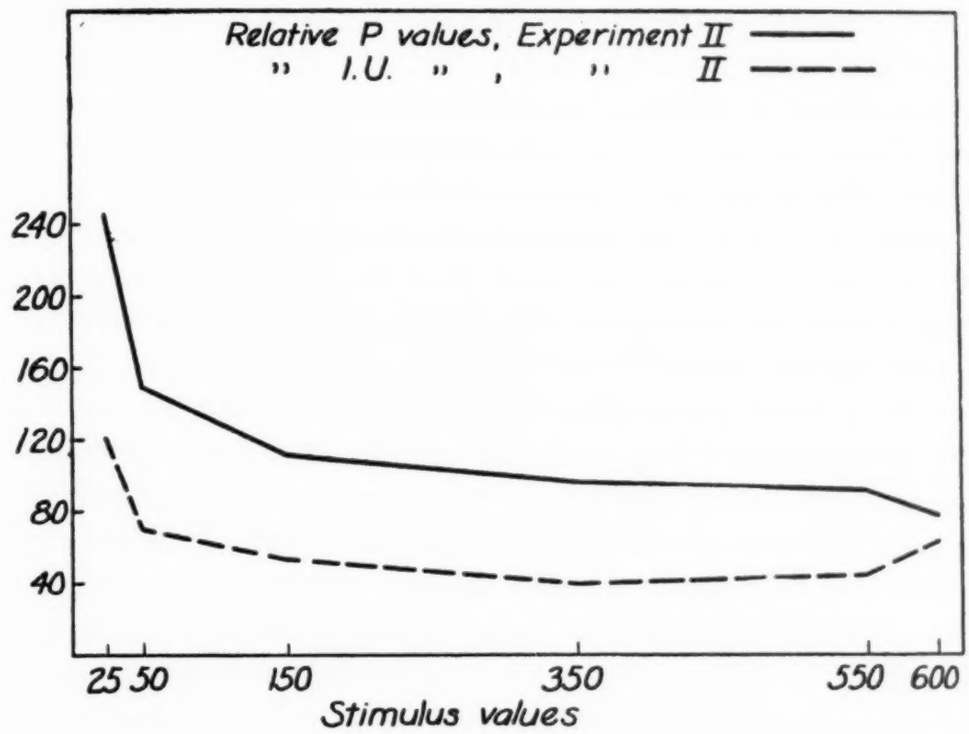
A comparison of the relative P-values in Table IX with those in Table VI shows that there is quite good agreement between the two experiments in which the weights employed were variable. This agreement seems the more remarkable

when it is considered that the subjects and their instructions were both different in these two experiments. The agreement between the relative P-values for the two experiments is shown graphically in Fig. 2. With such close correspondence of the two curves, it cannot be doubted that the P-values, or the relative P-values, for the two experiments are comparable measures, in spite of the fact that there were no 'equal' judgments admitted in one experiment, while there were in the other. Figure 2 also presents the curve for the relative



I.U. values. Here, these values are only about half the size of the relative P-values and, for the heaviest set of weights, the relative I.U. values rise while the relative P-values decrease. There is fairly good agreement in the shape of the curves with this exception. It seems perfectly safe to assume that the P-values furnish a measure of discriminability, in addition to their being a measure of the variability of the judgments. Culler has already demonstrated the relationship between P, as a measure, and L, as a measure (**5**). He offers four reasons for his preference for P. First, P is more reliable; second, P avoids any difficulties of the 'doubtful'

judgment, since it is not necessary to accept judgments in the intermediate category when using this method. Third, the P-method makes the observer more cautious; and, fourth, P is more simple and convenient to compute than is L. He made a comparison of the true limen, L, with P when both were derived from the same data. This showed that the conclusions based on L are borne out by P, and, although the absolute values for the L's were smaller than those for the P's, the relationships between the members of a series of L's were the same as the relationships between the members of a series of P's.



The results of the present experiments bear out Culler's conclusions. He stopped with the values of absolute P and L, because he was not testing at many or widely separated levels of the stimulus. The experiments presented here yield evidence of the agreement between relative P and relative I.U. over a rather wide range of the stimulus. (See Fig. 3.) Here it was necessary to use the relative values rather than the absolute ones, because the chief interest was in

finding the variability of these measures with a change in weights, rather than their variability among subjects.

A scrutiny of the curves for relative P and relative I.U. when plotted against the stimulus shows that there is not constancy of sensitivity over the whole range of stimuli. In fact, using either of these measures, the ratio of sensitivity for the lower stimuli to the medium stimuli is one to three. The shape of these curves agrees with the results of previous investigators in the field of sensory discrimination.

Hecht, after building an hypothesis about the visual sensory system, wanted to find the basis of Weber's law in terms of it. He started this by investigating the intensity discrimination of certain animals experimentally. In experimenting with the clam, Mya, he was able to measure the discriminative response to the intensity of light. This he did by adapting the clam to certain amounts of illumination and then measuring the reaction time of the retraction of the siphon with varying amounts of change in light intensity. With this technique, he found that the Weber fraction, dI/I, was not at all constant. He found, however, that this ratio has a regular mode of variation (**6**).

In a later paper (**7**), Hecht shows that his results with Mya are compatible with the results of other experiments done within the last seventy years. In all of these, the Weber ratio, dI/I, has the same mode of variation. In this paper, and in a still later one (**8**), Hecht presents the results of experiments done by Aubert, Koenig and Brodhun, and Blanchard. These results are presented in a way to show the relationship between the value of dI/I and the logarithm of the intensity of the stimulus. There is very close agreement between the three sets of results, and the values of dI/I decrease rapidly as the strength of the stimulus increases, in the case of weak stimuli; then there is a range during which the values remain quite constant, but with stronger stimuli there is a tendency for the values to increase.

Koenig and Brodhun have done, perhaps, the best experimental work on the measurement of dI/I (**11**). Their measurements were taken over the whole range of intensities,

from the lowest perceptible brightness to the point where the illumination becomes painful. Their results agree closely with those of Aubert, but are more extensive. They investigated higher intensities than did Aubert and they found that the ratio, dI/I, starts to increase again when the value of the stimulus gets beyond the intermediate range into very high intensities. Blanchard (**1**) later repeated these experiments with another method and obtained the same results. There is further and more recent evidence against the constancy of the ratio, dI/I, in vision (**3**). In fact, it seems to be only approximately constant even within the intermediate range of intensities. Measurements of it in several independent investigations show it to vary always in the same way.

Evidence for the existence of a similar relationship between stimulus strength and discriminability of intensity in the auditory modality is presented by Troland (**13**). The Weber fraction is shown to be very much greater for the lower intensities than for those in the medium range, where it approaches constancy.

Crozier and Pincus found, working with the geotropic behavior of rats, that the angle of orientation on the inclined plane varied when the angle of the incline varied, but the relationship was not constant (**4**). The angle of orientation can be thought of as being the response of the animal to a certain amount of pull of gravity which is furnished by the angle of the plane. This, and the fact that the angle of orientation is also a measure of excitation, has been pointed out by Hoagland (**9**). Graphically, from the results of these experiments, the relation between excitation and the logarithm of the intensity of stimulation is represented by an ogive curve.

Since measurements of acuity in relation to amount of stimulation, in various fields, yield results in close agreement, this relationship seems to be established. The problem then becomes one of explaining the relationship, *i.e.* the shape of the curves.

The most reasonable explanation seems to lie at the physiological level. Hecht explains his results by making visual acuity dependent upon the number of elements (rods and

cones) functional for any particular strength of stimulus. A normal distribution of stimulus thresholds in each set of elements is assumed. The sigmoid curve is, thus, the result of the fact that at low strengths of the stimulus there are only a few elements functional, and discrimination is poor; at very great strengths of the stimulus, discrimination becomes poor again as the limit of available receptors to be brought into function is approached.

The sigmoid curve, then, derives its characteristic shape from the relative paucity of receptors with extremely low stimulus thresholds and of those with excessively high stimulus thresholds, since it is only the integral of the distribution curve.

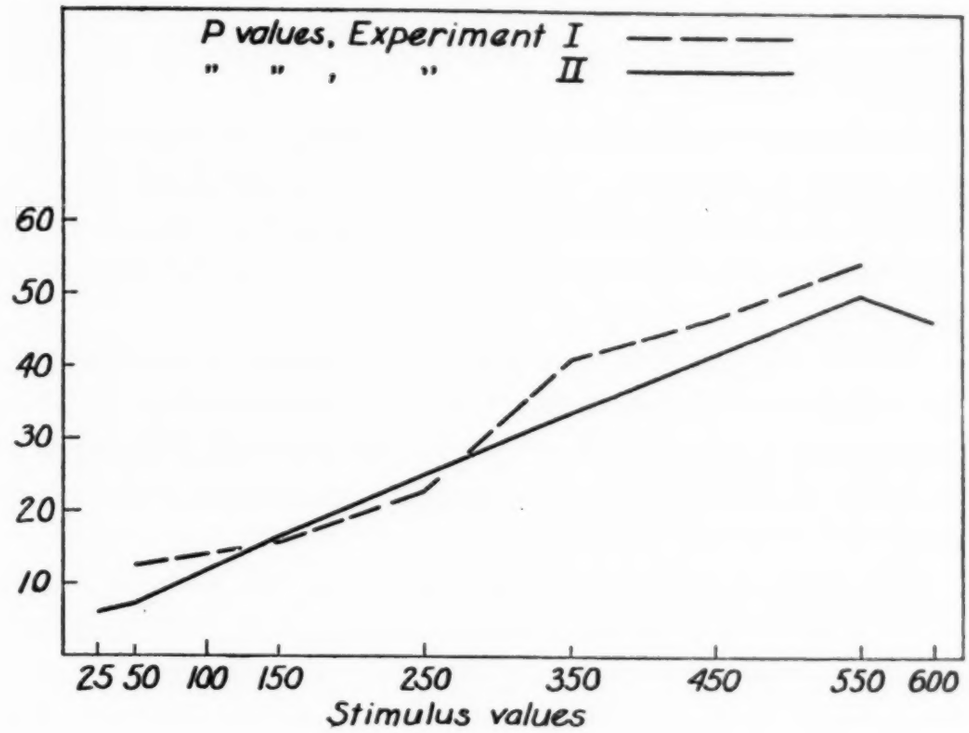
This explanation applies equally well to the results of Experiments I and II, presented in this paper, since the curves for these (Figs. 4 and 5) and for Hecht's experiments are essentially similar. The receptors, the stimulus thresholds of which are normally distributed, are, in this case, muscle-fibers.

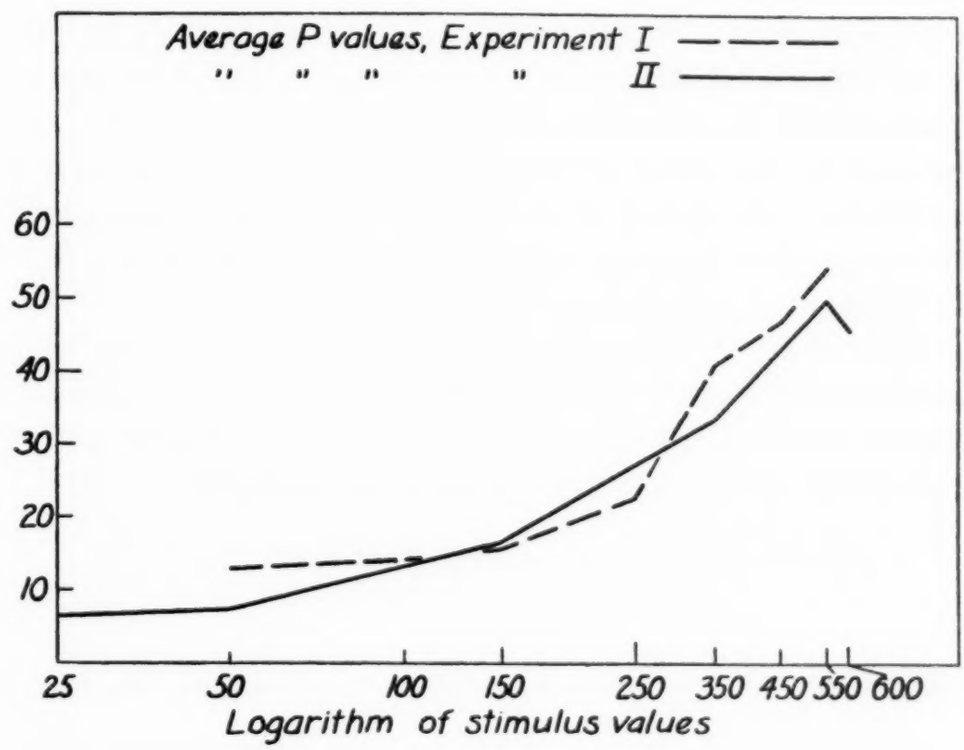
The assumption that sensitivity is dependent upon the number of muscle-fibers functional is also applicable to the results of the preliminary experiment. Since the shoulder movement included movement of the wrist and elbow, it is probable that more muscle-fibers were involved. If sensitivity varies with the number of muscle-fibers in use, greater sensitivity with proximal movement is to be expected. The results of the preliminary experiment show this to be the case.

Conclusions

In summarizing the results of the present experiments, the following conclusions may be stated:

The relative values of P, the probable error of the distribution, and the interval of uncertainty show themselves, graphically, to be essentially the same, so either may be used as a measure of discriminability. The close agreement between I.U. and P in Experiment II, as well as the agreement between the P-values of both Experiments I and II, shows that the use of the intermediate category of judgment, re-


P values, Experiment I
" " , " II
60
50
40
30
20
10
25 50 100 150 250 350 450 550 600
Stimulus values


Average P values, Experiment I
" " " " II
60
50
40
30
20
10
25 50 100 150 250 350 450 550 600
Logarithm of stimulus values

quired by the I.U. method, is unnecessary. The easier computation of the P-method makes it preferable to the I.U. method.

Sensitivity is greater with proximal movement than with distal movement. Using the I.U. method in the preliminary experiment, the results show that the values of I.U. were smaller for the shoulder movement than for the elbow movement.

Within certain limits, sensitivity increases with the absolute weight of the stimulus. The relative values of P in Experiment I, and I.U. and P in Experiment II, decreased as the value of the weights approached the middle of the range used.

The mode of variation in sensitivity found in these experiments is what would be expected if the threshold values of receptors were approximately normally distributed. This is particularly evident in the curve which represents the relative I.U. values. These values decrease as the stimuli used increase from the lowest to the medium strength. Furthermore, increase of the stimuli beyond the medium strength is accompanied by an increase in the value of relative I.U. A decrease in the value of relative I.U. means an increase in sensitivity. As shown in the discussion, these results justify the assumption that the stimulus thresholds of muscle-fibers are distributed, approximately, normally.

Constancy of kinaesthetic acuity is not upheld by these experimental results. This conclusion is warranted since the relative values of both P and I.U. have been found to vary extensively with a variation in stimulus strength.

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THE EFFECT OF NON-INFORMATIVE SHOCK UPON MAZE LEARNING AND RETENTION WITH HUMAN SUBJECTS

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Numerous investigations have been made of the effect upon maze learning, of electric shock or other forms of 'punishment' administered for error (**7**, **9**). Almost without exception the giving of a shock accompanying or immediately following the commission of the error has been found to facilitate learning. In such situations the shock would seem to have a definite signal or guidance value, as for example in the ordinary stylus maze, where it informs the subject that he is in a blind alley. However, failure of shock for error to facilitate learning has been reported in cases where a 'punch-board maze' was employed and the shock was given in addition to the customary bell or buzzer sound as a signal for error. Tolman, Hall and Bretnall (**12**), and Muenzinger (**11**) have reported such negative findings and Crafts and Gilbert (**2**), while reporting superior achievement for a group of subjects learning the traditional type of stylus maze with shock for error, found subsequently (**3**) that an auditory signal for error was quite as effective as the electric shock had been.

A few studies have been made of the effect upon retention of giving shocks for errors made during learning. Crafts and Gilbert (**3**) have reported superior retention for subjects learning with shock for error, as have also Bunch and McTeer (**1**). However, the former investigators found no differences in retention scores between those learning with shock for error, and those learning with auditory signal substituted for shock.

We may therefore well ask, with Muenzinger (**11**), has the shock any motivating effect which would bring about facilitation of learning and, perhaps, improvement of re-

tention over and above that attributable to its signal or informational value? In the present experiment an attempt is made to answer this question by determining the effect upon the learning and retention of a stylus maze habit of employing shock for error in learning in such a manner that the shock is deprived as completely as possible of its signal or informative function.

METHOD

Subjects.—The subjects were fifty-two undergraduate students at Washington Square College, New York University, constituting a single experimental group, performing under the conditions described in this report. Their performance will be compared with that of a control group and two other experimental groups used in experiments reported earlier (2, 3). These groups may be summarily described as follows:

1. Control group numbering fifty subjects. The subjects in this group learned the maze without any stimulation other than that afforded by the maze itself.

2. First shock group, fifty subjects. The subjects of this group were given electric shocks automatically when the stylus touched the end of any blind alley.

3. Auditory signal group, fifty subjects. In place of the shock, a click accompanied by the sound of a buzzer was substituted as a signal for error.

4. Non-informative shock group, fifty two subjects. This group, which was that of the present experiment, learned the same maze without any specific signal for error, but an electric shock was given for every ten errors during the early trials and for every five errors during the latter part of the learning process. The group was similar to the other three as regards chronological age, class of origin, etc. In all groups there were as many male as female subjects.

Apparatus.—The maze employed was the McGeoch-Melton medium maze, cut from three-ply veneer, 8.5 by 11 inches, and mounted on a bakelite base. The apparatus was arranged exactly as described in our previous article (2), with the following exceptions; the brass contact plates at the ends of the blind alleys were disconnected and a telegraph key was placed in the primary circuit of the inductorium so that the shock could be controlled by the experimenter instead of being given automatically. The special stylus used was that described in earlier reports (2, 4).

Procedure.—Excepting the mode of giving the shock, the procedure was the same as that employed with the experimental groups of our earlier studies. The criterion of learning was, as before, to traverse the maze two out of three successive trials without going so far into a cul-de-sac as to reach its end.

The subject was informed before the experiment began that he would receive electric shocks from time to time as long as he continued to make errors. The experimenter endeavored to make it clear to the subject that while shocks were administered for the commission of errors, they would *not* inform him as to where errors were made; he was told that shocks might be felt as often when he was going right, as when he was entering blind alleys and that a shock would mean simply that he was still making errors, and not that he was in a blind alley at the time of receiving it.

During the early trials, a shock was given as soon as the subject had made ten errors (*i.e.*, ten entries into blind alleys to the extent that the stylus touched the end of

the alley). Such errors have been referred to as 'contact errors' in our previous papers, and this terminology will be retained in the present paper. A second shock was given when the subject had made ten more errors, and so on. During the latter part of the learning series, when the number of errors per trial was small, the shock was given for each group of five errors. Because of the great amount of variability as regards the number of trials required for learning, the slope of the learning curve, etc., it was found impossible to formulate any useful general rules for determining just when to begin administering shocks for groups of five errors.

A few subjects who could not learn the maze within sixty minutes actual working time, or who had made no progress after an hour in the laboratory, were classified as failed, and their records were discarded. The number of such failures was the same as in the first shock group (group 2 described above), namely 8. There were six failures in the control group.

After an interval of one week the subjects relearned the maze to the same criterion, but without shock for error. A majority of subjects expected a retention test at the second sitting, and admitted having tried to recall the pattern during the interval, but the amount of such expectation and recall was probably neither greater nor less than that in the groups with whom the present subjects are compared.

After having learned the maze each subject was asked the following questions:

1. Was the shock annoying?
2. Did you try to avoid making errors so as to avoid getting shocks?
3. Do you think you would have done better without the shock?

RESULTS

The results for learning are presented in Table I.

TABLE I

LEARNING

Giving the means and the standard deviations for the four groups compared, together with the critical ratios of the differences.

	Signal Group (III)		Shock for Each Error (II)		Shock Without Inform. (IV)		Control Group (I)		Diff. / σ Diff.				
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	I III	I II	I IV	II III	II IV
Trials	15.5	8.58	17.2	8.40	22.63	9.7	23.3	8.74	4.51	3.52	0.34	0.93	3.02
Contact errors	120.9	63.36	127.4	70.74	161.73	64.11	220.0	114.10	5.47	4.89	3.16	0.48	2.6
Retracings	162.7	94.06	135.6	110.97	99.2	59.19	218.7	139.23	2.36	3.30	5.56	1.51	2.08
Time	1502.0	675.70	1438.0	636.90	1437.00	556.00	1804.0	797.00	2.43	2.54	2.68	1.25	0.0087
Two final trials													
Entrance errors	1·02		0.92		0.68		0·52						
Retracings	0.66		0.48		0.115		0.55						
Time	31.8		29.6		26.7		28.1						

The group working with the non-informative shock is reliably superior to the control group according to all criteria with the exception of trials. This group is, like the other two experimental groups, less variable than the control group

with respect to all measures except trials. It is inferior to the two groups in which the guidance factor was present (Groups II and III), as regards trials and contact errors, but superior with respect to retracings and equal with respect to time.

The verbal reports of the subjects of the non-informative shock group may be summarized as follows; thirteen made definite statements indicating that the shock was annoying, while an equal number stated that it was only slightly annoying. Seven recalled having tried to avoid the shock, while seven said they had worked to finish the task rather than to avoid getting shocks. Only six expressed the belief that they would have done better without the shock, and twenty-two voiced the opinion that the shock made no difference to learning; one alone reported that the shock greatly disturbed learning. Two reported that the shock 'woke me up' and therefore aided them in learning, while fourteen thought that the shock facilitated learning in some undefined way.

The results of the retention tests are given in Table II.

Discussion

(*A*) *Learning.*—We have, in previous reports, discussed the superiority of the original shock group and the auditory signal group to the control group according to all criteria—trials, errors, retracings and time. The data of Table I would seem to indicate that electric shock for error may have a facilitating effect upon the learning of a stylus maze even when it is administered in such a way that it gives no specific information concerning the location of and entries into blind alleys. Group IV, the 'non-informative shock' group, surpasses the control group in point of errors, retracings and time, the differences between the means having a fair degree of statistical reliability. It will be seen that this group stands between the control group and the other two groups with respect to 'contact' errors—that it stands about on a par with the control group in point of trials, surpasses all the other groups as regards retracings, and does not differ

from Group II, the original shock group, with respect to time.

We may also note that the variability of this new group is less than that of the control group for all measures with the exception of trials.

TABLE II

RETENTION

Giving recall, relearning, and savings scores

	Signal Group (III)		Shock for Each Error (II)		Shock Without Inf. (IV)		Control Group (I)		Diff. / σ Diff.				
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	I III	I II	I IV	II III	II IV
Recall													
Errors	3.4		4.9		4.2		5.3						
Retracings	2.1		3.3		1.43		4.2						
Time	49.9		58.9		36.3		52.8						
Relearning													
Trials	5.6	3.87	5.7	6.49	6.75	5.57	7.6	6.62	1.84	1.49	0.72	0.02	0.88
Contact errors	15.9	15.25	16.6	19.78	16.49	15.3	20.7	21.55	1.29	1.00	1.13	0.19	—
Retracings	7.4	10.82	7.3	8.21	4.2	6.4	15.3	25.00	1.95	2.14	3.03	1.51	2.12
Time	230.8	180.00	188.5	155.40	187.0	136.0	244.8	187.77	0.38	1.63	1.78	1.25	0.05
Percent Saving													
Trials	63.9		66.9		70.0		67.2						
Contact errors	86.8		86.9		90.0		90.6						
Retracings	95.5		94.6		95.6		93.0						
Time	84.6		86.6		87.0		86.2						
* *Percent Saved per Trial, Error and Second of the Learning*													
Trials	4.12		3.89		3.09		2.98						
Contact errors	0.72		0.68		0.56		0.41						
Retracings	0.59		0.64		0.96		0.45						
Time	0.056		0.061		0.061		0.049						

* These figures are obtained by dividing the percent saving in trials, errors, etc., by the number of trials, errors, etc., required for the learning.

Elsewhere attention has been called to the fact that there are no significant differences between the original shock and the auditory signal groups (Groups II and III respectively). This is in agreement with the findings of Tolman *et al.* (**12**) and Muenzinger (**11**). Both investigators, using a 'punch-

board maze' having thirty pairs of holes, report that there are no significant differences between the groups learning with shock and bell for error, and those learning with bell alone. The conclusion drawn is that the shock functions only as a signal or emphasizing stimulus. However, in animal experiments different results have been obtained. Muenzinger (**10**) trained three groups of white rats on a simple black-white discrimination, with shock for errors, shock for correct responses, and no shock, respectively. Both groups trained with the shock were much superior to the group trained without it, but there were no significant differences between the group shocked for error and the group shocked for correct response. This difference in the results for human and animal learning is explained by Muenzinger in terms of differences in general motivating factors. The rat is motivated chiefly by the hunger drive, which is seldom at its maximum strength; therefore an additional motivating factor such as an electric shock may facilitate learning. On the other hand, human subjects ". . . are so well motivated already that the addition of the electric shock has no effect upon their learning efficiency." He continues, "If this assumption be correct we should conclude that human subjects do not provide us with a sufficiently significant experimental situation for a study of the accelerating effect of electric shock in learning" (**11**).

We have elsewhere suggested (**3**) however, that, in our stylus maze experiments at least, both shocks and auditory stimuli have functioned as incentives as well as guides. Both have seemed to us to fit Leuba's (**7**) definition of an incentive as any stimulus which arouses or augments the incentive attitude—i.e., a 'source of energy' leading to movements which are faster, more vigorous, more persistent, and more uniformly relevant to the task at hand, and as we have previously pointed out, the fact that there are no significant differences between the signal and shock groups certainly does not necessarily mean that both shock and auditory signal have only an informative value, or that the shock does not have a greater incentive value than the auditory signal has.

It is possible that while a shock of the strength given in these experiments constitutes a motivating stimulus for many subjects, it is a disrupting and disorganizing one for others. If, in the group means one of these two effects were counterbalanced by the other, the net average result of the shock would be the same as that of the auditory signal.

Although in the earlier experiments we had only a priori considerations and the subject's verbal reports to suggest that the shock may have an incentive as well as an informative value, in the present study we obtain definite objective evidence that such is indeed the case. At first glance it might seem that if the non-informative shock group performed on a higher level than the control group, indicating a motivating effect for the shock, the original shock-for-error group should have been superior to the auditory signal group, indicating an incentive or motivating value for the shock over and above its signal value. However, plausible reasons for this seeming inconsistency are not difficult to find. It may very well be that electric shock as given in the original shock group, *i.e.* a shock for each error at the time the error was made, has a greater disrupting effect in the early stages of learning than does the non-informative shock. Subjects in the original shock group situation begin to enter blind alleys and therefore to get shocks almost immediately after starting out on the first trial, and in many cases the effect may be to arouse disrupting emotional responses before the subject has had a chance to become fairly adjusted to the new type of situation. The subjects of the non-informative shock group do not receive the first shock until they have made ten errors. This gives them a chance to become oriented, in a general way at least, before the first shock is given, and the emotional inhibition or disorganization may therefore not be as great. Furthermore, the subjects of the shock-for-each-error group receive shocks much more frequently than do those of the non-informative shock group. This means that those of the former group are more disturbed, *i.e.*, the shock has a greater negative effect during the first few trials, but that they become more or less adapted later on, so that the shock has less

effect, either positive or negative, during the latter part of the learning process. On the other hand, the non-informative shock subjects do not become so adapted. Their shocks are more widely spaced, and they more often take the subject by surprise. The verbal reports of some of the subjects indicate that under such conditions the shock 'wakes them up,'—that is, reinstates from time to time a more favorable attitude making for more adequate response to the available cues.

It is clear that the effect of shock for error is dependent upon the manner in which the shock is administered. It is highly probable that much more intense shocks, or shocks given much more frequently than in the present experiment would have different effects upon learning.

As to the way in which the non-informative shock operates to facilitate learning in the case of our human subjects, it would seem that an interpretation similar to that given by Muenzinger (**10**) with reference to his animal data would be acceptable. He writes that ". . . the function of moderate electric shock in the visual discrimination habit is general rather than specific, . . . it affects the total performance rather than the part-response it accompanies. In other words, its function is to make the animal respond more readily to the significant cues in the learning situation rather than that of inhibiting or facilitating the response which was shocked." Not incompatible with this, but rather supplementing it, is Guthrie's (**5**) explanation of the emotional reinforcement of learning. This writer, whose interpretations are given in terms of the conditioned response, stresses the importance of proprioceptive stimuli as 'conditioners.' ". . . Exciting emotion involves the quick relief of fatigue through the direct action of adrenine on muscle tissue. The muscle so affected responds with greater contraction to the same motor impulses and by its greater contraction stimulates new fields of proprioceptor sense organs in the muscles and the joints and tendons. These added stimuli may become conditioners of movement and hence explain the increased certainty of conditioning. Movements during excitement are more complete and vigorous than movements during un-

excited states. In excited movement there are new movements to be conditioned as well as added conditioners for movement. The strong tendency for movements executed during excitement to become stereotyped into habits may have this explanation" (*op. cit.*, page 105).

(*B*) *Retention.*—The 'non-informative shock' group is superior in retention to the control group according to all criteria. While it is not possible to present any differences which are greater than three times their standard errors (with the exception of that for retracings in relearning), causing us to formulate conclusions with extreme caution, nevertheless the fact that the present experimental group is slightly superior according to *all* criteria would suggest that through the use of larger groups these findings might be confirmed.

Of the measures of savings, the per cents saved per trial, error, and second of time of original learning are probably more significant than the conventional percent saved values, because the shock group learned in a shorter time and with fewer errors than the control. Therefore the contribution to retention of every learning error or second of time is greater for the shock group.

As to why additional motivation during learning should improve retention, we can add little to the suggestions of Bunch and McTeer (**1**), and Guthrie (**5**). Bunch and McTeer suggest that the shock induces something like Leuba's (**7**) 'incentive attitude,' involving increased muscular tension, and more rapid and vigorous movements. This, they indicate, may result in a—'more definite integration of the acquired activity';—or, as they also suggest, the decrease in errors and other unnecessary activity which shock typically produces, brings about a—"greater difference between the functional strength of the acts 'selected' and that of the acts 'eliminated.'" In line with Guthrie's conditioned response interpretation, we might assume that when any stimulus, such as shock, brings about more vigorous response to the learning situation, more proprioceptive stimuli are furnished at any particular stage, for following movements to become

conditioned upon. This increases the chances of having, at some later time, at least one of these proprioceptive 'conditioners' revived to elicit the response in question. Space does not permit us to enter into a detailed discussion of the extent to which such interpretations may be developed, and the reader is referred to Guthrie's recent book for a more adequate treatment of these theoretical questions.

Summary

The aim of the experiment was to determine the effect upon the learning and retention of a stylus maze of electric shock for error, given in such a way as to eliminate the guidance factor. The subjects were 52 college students, who learned the McGeoch-Melton Medium maze to the criterion of two out of three successive trials without error. An electric shock was given for every ten errors during approximately the first half of learning, and every five errors thereafter. The subjects relearned the maze after an interval of one week. The mean number of trials, errors, retracings and seconds were compared with the corresponding means for a control group, and previously run groups in which shock and auditory signal for error, respectively had been administered.

The 'non-informative shock' group is superior in learning to the control group according to errors and time, but not with respect to trials. It is inferior to the other experimental groups in point of trials and errors, but equal to them as regards time.

In retention the 'non-informative shock' group surpasses the control group according to all measures. The differences, while not statistically reliable, are consistent.

It is concluded that electric shock *may*, under certain conditions at least, have a facilitating effect upon learning apart from its guidance value, and that there is evidence (though less positive) that learning motivated in this way is followed by better retention than that which follows less highly motivated learning.

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THE EFFECT OF DISTRACTION UPON SERIAL POSITION VALUES IN RETENTION

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Introduction

Robinson and Brown (**6**) and many others have demonstrated that the ease of learning a series of acts varies with the serial segment. Most easily learned are the initial segments. The final segments rank next and the most difficult segments are in the late middle zone. Several recent experiments have sought to discover whether or not similar relations are to be found between serial position and retention. Ward (**7**) in his study of the retention of serial acts over short intervals of time demonstrated that segments in the middle zone of partially learned series are known better two minutes after the cessation of practice than they are at the end of the practice period.[1] Ward also showed that this effect was possibly augmented by the interpolation of activity during the two minute forgetting interval.

McGeoch (**5**) has conducted several studies designed to investigate the influence of retroaction upon serial position values. His results show that retention as it varies from segment to segment is not a simple function of the ease of learning except when learning has been incomplete. More specifically they show that when the series are learned to mastery or near mastery the relative values of the two end positions, as indicated by ease of learning, are reversed in retention. That is to say, although the initial position is superior in ease of learning it is inferior as regards retention. Further, the values of the intermediate positions become more nearly equal to those of the initial and final positions than they are as regards ease of learning. Finally McGeoch has

[1] It is interesting to note that Hull (**1**) deduced and predicted this phenomenon before it was discovered.

shown that learning interpolated during the constant five minute forgetting interval augments the effects noted. The initial segment is shown to be more susceptible to retroaction than the final segment and the middle zone of segments is least susceptible of all. He concludes that ". . . individual items are not retained in anything approaching proportion to their correct frequency in learning." Witmer (**8**), in a study of remote association, has, in general, confirmed the results of McGeoch (**5**). She measured the retention of serial acts at intervals of five minutes, twenty minutes, twenty-four hours and one hundred and sixty-eight hours and found that at each interval, with the possible exception of the twenty minute interval, the final segments were better retained than the initial segments and that the retention of the middle segments was incommensurate with what one might expect on the basis of correct frequency in learning. Hull (**2**), in his study of the influence of caffeine on serial position values, has noted that: "The marked excess in difficulty of recalling the syllables in the late middle of rote series, so characteristic of learning by massed practice, disappears entirely after a period of some twenty hours of no practice." In his results the initial segments and the final segments are approximately equal in recall value after twenty and one half hours.

The simple experiment to be reported here was planned as a deliberate search for such phenomena as those noted above and was originally motivated as a test for certain implications which seemed to be logically generated by an hypothesis derived from a series of not unreasonable assumptions. To speak more specifically, the author, basing his line of thought upon theoretical considerations previously submitted by himself (**3**) and more elaborately by Hull (**1**),[2] predicted that *the apparent discrepancy between serial position values in learning and serial position values in retention, as noted above, would be increased when the tests of retention were conducted under conditions of distraction.*

[2] The theoretical development is too elaborate to be recorded here.

The Experimental Procedure

The experiment was planned as a straightforward experiment upon the retention of serially learned nonsense syllable materials with the special objective of measuring the effects of a distraction, administered during the test performance, upon serial position values. The experimental group was made up of twenty male undergraduates of The Pennsylvania State College. Each one of these men had previously learned and relearned twenty, twelve-unit nonsense syllable series in an earlier experiment. They were, therefore, thoroughly familiar with the general experimental procedure. The learning material consisted of four twelve-unit nonsense syllable series which were composed as described in a previous publication (3). These lists were presented by means of the multiple exposure machine described in the same article. This machine provided a constant exposure interval of two seconds. All learning and relearning was done by the anticipation method. The degree of mastery was held constant at one perfect performance. The forgetting interval was held constant at ten minutes. Each subject performed at the same time on each of his four consecutive experimental days. All of the original learning performances and one half of the relearning performances were conducted under conditions of no intentional distraction. One half of the relearning performances were conducted under conditions of distraction which were provided as follows. The subject wore a set of headphones which had a resistance of 2000 ohms and through which was passed an eighteen volt, sixty cycle, alternating current. The instructions to the subject and the general procedure as to the use of the apparatus were exactly as previously described (3). The first indication to the subject that the conditions of relearning were to vary came when the headphones were adjusted. The true nature of the variation was not known to the subject until the current was switched through the headphones three seconds before the cue syllable appeared in the first trial. This three second interval was constant for all trials under these conditions. Each subject learned and relearned each of the four lists. The order in which the lists were learned was constant. Ten subjects relearned lists one and three under conditions of distraction and lists two and four under conditions of no distraction. The other ten subjects relearned lists one and three under conditions of no distraction and lists two and four under conditions of distraction. Thus was an attempt made to hold constant possible practice effects and the effects of possible differences in the learning materials. In this manner were gathered the data which are summarily presented in the following section.[3]

Results and Interpretations

Table I and Fig. 1 are intended to show the comparability of the original learning performances, half of which were followed by relearning under conditions of distraction.

From the above data it appears to be legitimate to conclude that the original learning performances were essentially equivalent. At no serial position does the mean number of errors differ by more than 0.5. This is the difference value

[3] The first syllable was always given as a cue syllable at the beginning of each trial. Therefore the tables and graphs contain values for only eleven syllables.

TABLE I[4]

EASE OF LEARNING AS A FUNCTION OF SERIAL POSITION

The scoring of the original learning records was accomplished by summing the number of errors at each serial position. The serial position values presented here represent means of these summations. N = 20. Each value represents the mean of 40 measurements.

Conditions of Relearning	Serial Position											Mean Total Errors	Standard Error of the Mean	Mean No. of Trials	Standard Error of the Mean
	1	2	3	4	5	6	7	8	9	10	11				
No distraction	1.4	2.2	2.8	3.7	5.3	5.0	6.2	6.5	6.2	4.8	3.6	47.6	2.77	10.5	0.65
Distraction	1.5	2.4	2.7	4.1	5.0	5.4	5.9	6.4	5.7	4.3	3.5	46.8	5.01	10.5	0.95

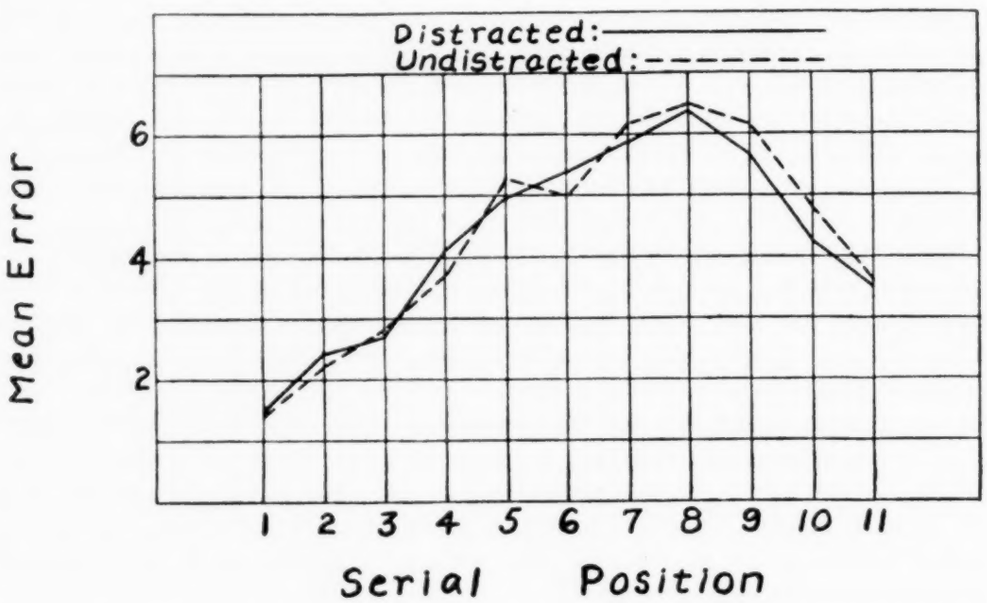

FIG. 1. Ease of learning as a function of serial position. This graph was plotted from the data in Table I.

for positions 9 and 10, at which points the original performances for the lists to be relearned under conditions of no distraction show an excess.

Table II and Fig. 2 and Table III and Fig. 3 are intended to demonstrate the effect of distraction upon serial position values in retention.

[4] The original records and the complete tables from which the tables appearing here were compiled are on file in the Department of Psychology of The Pennsylvania State College.

TABLE II

THE EFFECT OF DISTRACTION UPON SERIAL POSITION VALUES IN RETENTION

The saving scores upon which this table is based were computed by dividing the number of errors at each serial position in the relearning record by the number of errors at the corresponding serial position in the original learning record. N = 20. Each value in this table represents the mean of 40 measurements.

Conditions of Relearning	Serial Position											Mean for Total Lists (Error Scores)	Standard Error of the Mean	Mean for Total Lists (Trial Scores)	Standard Error of the Mean
	1	2	3	4	5	6	7	8	9	10	11				
No Distraction	95.8	97.1	88.8	83.9	89.7	85.5	87.4	87.6	85.3	91.9	93.9	89.3	3.12	71.9	2.81
Distraction	94.2	89.6	78.3	76.7	77.3	88.5	73.0	72.1	71.5	84.0	85.0	79.4	2.34	60.0	3.72

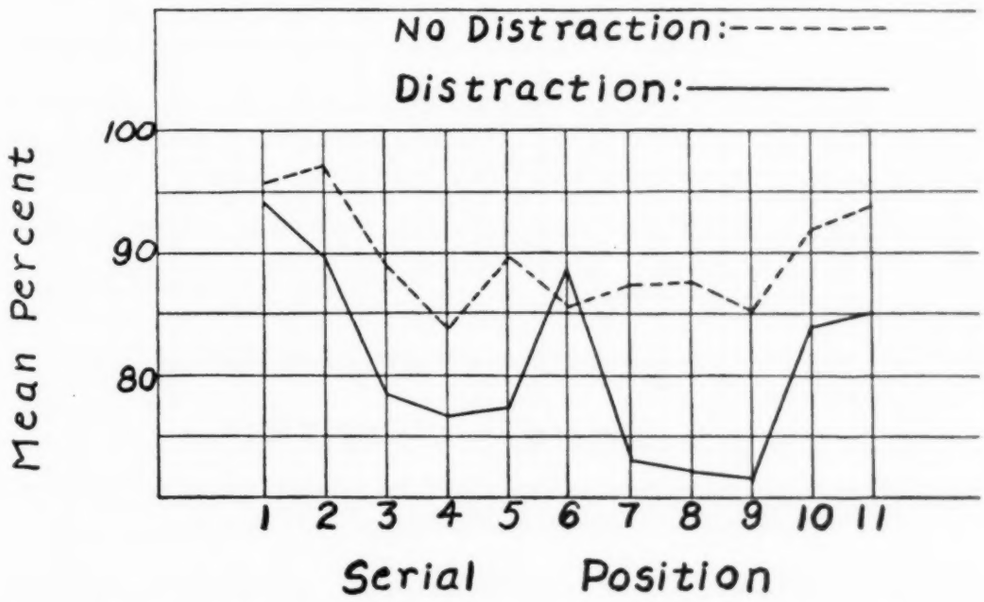

FIG. 2. The effect of distraction upon serial position values in retention. This graph was plotted from the saving score data in Table II.

A comparative examination of Figs. 2 and 3 reveals that the data from the recall score measurements are in approximate agreement with the data from the saving score measurements. The graphs all show a slightly superior retention for the initial positions. This is apparently out of harmony with the results of McGeoch (**5**) and Witmer (**8**). This may be due to differences in technique. The central zones are con-

TABLE III

THE EFFECT OF DISTRACTION UPON SERIAL POSITION VALUES IN RETENTION

The recall scores which this table summarizes were simply the first-trial scores in relearning records. N = 20. Each value in this table represents the summation of 40 measurements.

Conditions of Relearning	Serial Position											Mean for Total Lists	Standard Error of the Mean
	1	2	3	4	5	6	7	8	9	10	11		
No distraction	39	39	34	31	28	28	32	28	26	34	35	8.9	0.35
Distraction	37	35	30	26	25	28	23	20	20	31	35	7.8	0.32

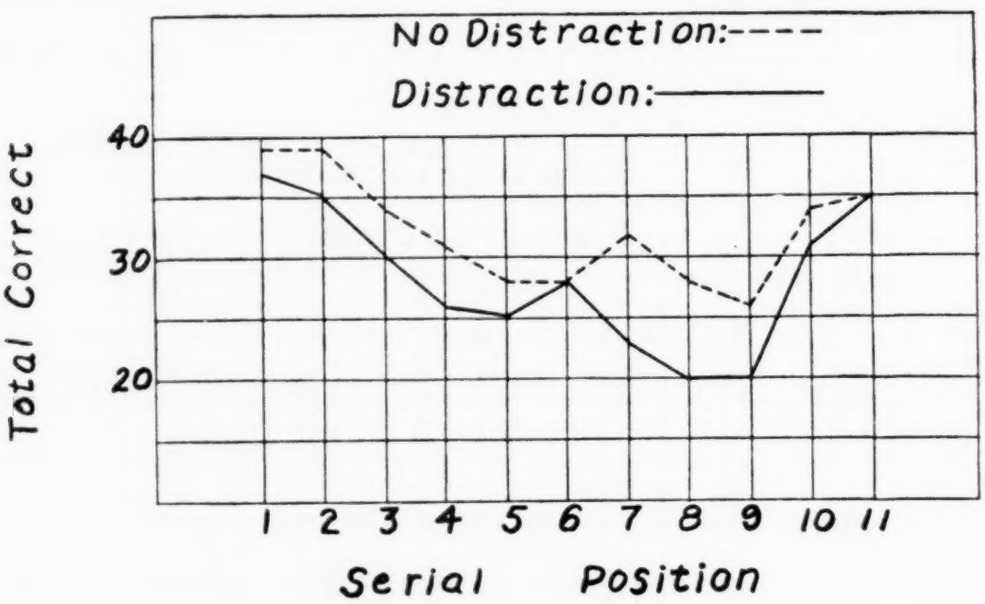

FIG. 3. The effect of distraction upon serial position values in retention. This graph was plotted from the recall score data in Table III.

sistently inferior except that here again appears the curious W-shaped graph previously reported (4).

Figures 2 and 3 appear to agree in showing that the greatest effects of distraction occur in the late middle zone, at segments 7, 8 and 9 which are shown, by Fig. 1, to be learned with the greatest difficulty. As indicated by the saving scores the final segments appear to be more susceptible to distraction than are the initial positions. As indicated by recall scores the final segments appear to be slightly less susceptible. This contradiction may indicate that there is no real difference.

In order to test for the prediction made that *the apparent discrepancy between serial position values in learning and serial position values in retention would be increased when the tests of retention were conducted under conditions of distraction*, rank difference coefficients of correlation were computed as follows:

1. Between ease of learning, as measured by the mean number of errors made at each serial position in the original learning, and the degree of retention under *conditions of no distraction.* This coefficient for saving scores turned out to be $+ .64 \pm .13$. For recall scores it is $+ .86 \pm .05$.

2. Between ease of learning, as measured by the mean number of errors made at each serial position in the original learning, and the degree of retention under *conditions of distraction.* The coefficients in these calculations are $+ .79 \pm .08$ and $+ .90 \pm .04$ for saving scores and recall scores respectively.

There is, perhaps, some question as to whether it is permissible to use correlation technique in this fashion, but if one assumes that it is legitimate then there is revealed no evidence whatever in confirmation of the foregoing prediction. Rather, there is an apparent contradiction and a potent suggestion that there is something amiss in the theoretical construct upon which the prediction was based. A simpler and possible explanation of this apparent increase in correlation is that it may be due to the decreased variability of the subject's performance on being tested for retention under conditions of distraction. This interpretation is consistent with the data on variability for the retention scores for total lists. The standard errors of the means for recall scores for total lists are 0.35 for the conditions of no distraction and 0.32 for the conditions of distraction. Those for error saving scores for total lists are 3.12 and 2.34 for conditions of no distraction and conditions of distraction respectively. Whether or not this latter interpretation is the correct one the above statement to the effect that there is no evidence for the phenomenon sought remains unaffected.

Summary

The limited and somewhat ambiguous results of this simple experiment, concerned with the effect of distraction upon serial position values in retention, suggest the following conclusions.

1. Serial position values in the retention of serial nonsense syllable materials are significantly correlated with serial position values in learning when the materials are learned to a criterion of one perfect performance.

2. There is some slight evidence that a constant distraction administered during the tests of retention increases the degree of relationship noted under 1 above. This may be due to the reduced variability of performance when the subject is tested under the more constant conditions of intentional distraction.

3. In this study, there is revealed no evidence in confirmation of the prediction made that *the apparent discrepancy between serial position values in learning and serial position values in retention would be increased when the tests of retention were conducted under conditions of intentional distraction.*

4. By 3 above it is indicated that the line of thought that led to the planning of this experiment is in need of reexamination and revision.

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THE RELATION OF RETINAL ILLUMINATION TO THE EXPERIENCE OF MOVEMENT *

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Light falling on the eye from a bright object stimulates not only the restricted portion of the retina spoken of as the image; but if it is very bright, a fraction falling on the sclera surrounding the iris upon diffusing through the eye walls to all parts of the retina is effective in stimulating it. Even a portion entering through the pupil is dispersed by the media forming a gradient of light surrounding the image. Ultimately light is reflected from the image to all parts of the retina, the eye acting as an integrating sphere. In the rabbit, the brightness ratio between image and remainder of the retina is 35 to 1 with a 5 mm pupil and a test object of 46° in visual angle. With the angle reduced to 7° a ratio of 600 to 1 might be expected (Bartley, 1935–*a*). Cortical action potentials under these latter conditions have strikingly shown the efficacy of this stray light even when supposedly insignificant.

The outcome of an optical situation of this sort is that there are two areas *coincidentally* illuminated at different levels with a graded area between them, which due to different latent periods depending on intensity send impulses to the higher centers *successively*.

In light of the fact that a succession of impulses from different retinal points is the basic cause of the experience of real movement, the present paper examines whether gamma movement [1] is caused in this way by the operation of entoptic stray light.

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[1] Gamma movement is the visual experience such as one obtains when observing light flashed on and off. When flashed on there is a movement of expansion in the visual field and when flashed off there is a contraction movement, as if the light all went from the room back into the source emitting it.

Apparatus.—The following apparatus was used to produce a large stimulus field which was homogeneous in brilliance to the eye but which in exact terms was only 95 percent as bright at the periphery as at the center. However, when the light was switched on, all parts of the field were illuminated simultaneously, avoiding any possible perception of movement due to the artifact of successive illumination.

The image of an opal glass disc 2½″ in diameter in the wall of the lamp house was projected on a second opal glass plate by a pair of biconvex lenses 3″ in diameter placed ½″ apart midway between the two glass surfaces which were at the conjugate foci of the lenses. A revolving disc with appropriate open sectors passed between the two lenses intermittently passing and obstructing light. Beyond the second glass surface was a third, 12½″ square on which was a black card with a hole 11″ in diameter forming the stimulus field for the observer. The lenses and light paths were housed to minimize the stray light in the room, which was otherwise unlighted in all of the experiments save in the occasions when a dim light was projected on the stimulus field formed by any one of the various cards used over the original large aperture. These patterns will be described as the occasion arises.

Experimental.—If the spatial-intensity pattern of retinal illumination is to determine the nature of the optic nerve discharge, and thus control what kind of movement will be seen, an examination of the distribution of retinal stimulation instituted by the commonly used stimulus patterns is first in order. The diagrams which follow in Fig. 1 call attention to eight quite different cases typical of the necessary retinal

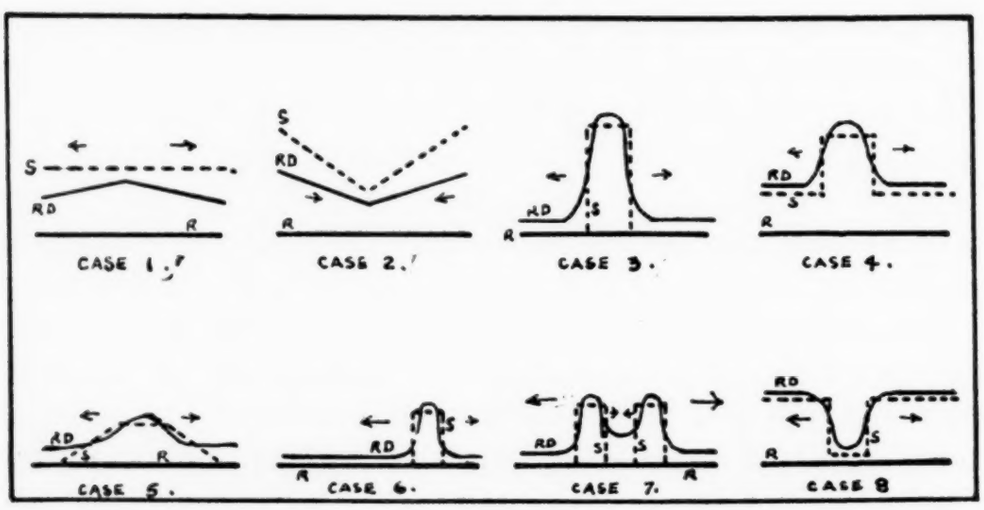

FIG. 1. Eight typical cases of distribution of light in the stimulus pattern with their respective retinal distributions. Dotted lines S show the stimulus, and lines *RD* the retinal distribution. The base line *R* in each case is the retina with vertical distances from it indicating intensity. The arrows show direction of the observed movement. Note that in no case are the retinal and stimulus patterns identical due to stray light from several sources.

conditions for the seeing of movement. The distributions are those that would be expected from the already existing studies bearing on the distribution of entoptic stray light, particularly the one by Bartley and Fry ('34).

In each diagram the heavy base line represents the retina with no illumination while the curves above it represent distribution of light, the dotted line for the stimulus, and the solid line for the consequent distribution on the retina. In some cases the

light in the stimulus was confined to a small portion of the visual field but in all cases the consequent retinal distribution covered the entire retina, so that the whole retina is to be taken into account regardless of the visual angle subtended by the test-object.

To demonstrate whether or not gamma movement occurs with a homogeneous visual field, one need only to place the eye about an inch away from the unreduced aperture of our apparatus as it is alternately lighted and darkened. Under such conditions definite expansion and contraction movements of the usual kind and in the usual direction are observed.

In such a situation (case I) it is to be noted that even though the visual field is equally bright in all parts, the illumination of the retina produced by it is not uniform due to the following factors. The pupil does not transmit an equal amount of light through all its parts (Stiles and Crawford, '27) and less of the light falling obliquely on the eye from the periphery of the field will pass into the eye than that falling on it from the center on account of greater corneal reflection. And also the effective pupillary opening is not as great for light entering the eye obliquely as for light entering at the normal. The movement then is due to these factors and to the possible difference in the latent period of the rods and cones which reciprocally populate the eye from fovea to periphery (McDougall, '04).

If instead of using a homogeneous field, two spots equal in all respects are so placed that the image of one falls on the fovea, and the two are simultaneously presented, the foveal spot bursts suddenly into sight and expands rapidly. The other spot lags behind the first somewhat and expands more slowly. The movement concerned in the appearance of the first spot seems to be confined close to or within the spot itself while the movement in the other case spreads out to a greater extent employing the halo around the spot. At the same time there is a general field movement outward from the two spots. This demonstrates that when two points equal in all respects are simultaneously presented to vision, one at the fixation point and the other some distance away (10–15°), there is a temporal difference in the time of their appearance, this being equivalent to two stages of movement in a continuous field where a series of retinal points are stimulated in such a way as to discharge successively in time. The extent to which this

successive discharge in the case of the two spots is due to the difference in retinal structure or to the inequalities in the light cast on the retina cannot be determined. However, since it is possible that the rods have a longer latency than the cones it might be that the periphery is slower than the fovea in responding, a factor which would contribute to establishing a successive discharge even when all parts of the retina should be equally illuminated. In case two, the light in the stimulus field was graded so that the edge was much brighter than the center. The field was the full size of the original aperture and could be used with the eye close to or distant from it. When the pattern was illuminated gradually and viewed from, let us say, 6 inches away two sorts of movement could be distinguished. The first burst was outward at the edge of the pattern which did not fill the whole field of vision and the second was a slower inward movement as the light increased in brightness. In this experiment the brightness distribution is so arranged that instead of the foveal elements discharging first as is the usual case they discharge only after the peripheral elements stimulated by the edge of our pattern. Movement is in both directions, outward as well as inward for there are elements out beyond those stimulated by the edge of the pattern, as well as those at its center, which are weakly stimulated.

This experiment shows that expansion from the fixation point outward is not a necessary event as the field is made brighter. Expansion and contraction are relative to the point in the visual field most intensely illuminated whether it be in the neighborhood of the fixation point or at the edge of the field. In the present case the portion of strongest stimulation was a huge ring far out toward the edge of the visual field, the inner side of which ring was tapered off so gradually that the field in general did not appear to contain a ring but the pattern as first described. The geometry of the brightness gradients was so arranged that the observer was constrained to report discrete or unrelated movement in two directions, namely in toward the center of the field and outward toward its edge whereas if the pattern were considered

to be a ring the movement seen is simply an expansion movement from the ring itself.

Case three is a simple one representing one of the most usual situations. Here a one inch aperture is used on the apparatus and the eye is 12 or more inchesa way. Field (ground) movement as well as movement in the figure is noticed but may be reduced or eliminated by lighting the field so that the amount of stray light produced by the image is slight compared to the general light on the retina from the stimulus field. We have then the condition illustrated in case four. Case five is the virtual opposite of case two. In this, the point of highest illumination is at the fovea with a gradual tapering of the intensity toward the periphery making for the minimum distinction between figure and ground and a smoother movement. In case six, the quality of the field movement in the various directions from the test-object is made different by placing it eccentric to the fixation point. Such an eccentric placement brings into play whatever inequalities there may exist either in the functioning of the various parts of the retina itself or in the illumination of its different parts as due to factors described earlier in the paper.

Case seven consists in the use of two patches of light fairly close together. If they be rectangles and are separated by a distance equal to the width of one of them, the conditions are quite like those in one of Newman's ('34) experiments which he used to demonstrate that the direction of movement depended upon the part of the visual field seen as figure.[2] The protocols given by his observers were incomplete in their information but can, with certain qualifications, be made to agree with our observations.

The movement that occurs in this situation is complicated. There is a broad movement from the fixated area between the two rectangles, a point corresponding to the geometric center of the test-object, and the general region of greatest illumination. If this black rectangular area is seen as figure the observer can well say that he saw the area expand as it came into

[2] The fact of stray light falling on areas seen as black contradicts the statement of Newman that all of the 'objective' change in stimulation occurred external to this black area seen as figure.

existence. There are included within this broad expansion two minor expansions outward from the lighted rectangles. A clear cut complete report includes both of these movements, the broad general one as well as the local ones. It is natural that a given observer may make vague or incomplete statements about so complicated an event, but this does not vitiate the differential rôle played by the retina in determining the character of movement any more than it does in ordinary brightness vision when an observer fails to note that one surface is brighter than another, in a field of several brightness levels.

Case eight represents the essential conditions of Harrower's ('31) *Lochversuch* in which a black object [3] was made to appear or disappear upon a white ground. In this situation the object can be seen to expand upon appearing, expansion under such conditions having been taken to prove the dependence of movement upon the appearance and disappearance of a figure rather than upon the nature of stimulation changes in the retina. This and the other experiments mentioned were taken to show that expansion in a given portion of the visual field could occur whether or not any change in intensity of stimulation occurred there and so did not depend to any great degree if at all on a retinal process. As has been said before this conclusion rests in part on the erroneous assumption that the only part of the retina receiving light is the image, and the consequent failure to determine what happens when unequal amounts of stimulation are withdrawn from two areas is is the case in the present experiment. The diagram for this case makes it clear that at the center of the image more light is withdrawn as the object looms into existence and becomes blacker than is withdrawn at its borders. There are some very indirect experiments in the literature which tend to show that reaction is more rapid when a greater amount of stimulation is withdrawn than when a lesser amount. However, an experiment bearing more directly upon the subject is as follows. The midpoint between two small bright spots

[3] According to some, if it were not for its figure properties, the object when black should look to contract when presented rather than expand as does a bright object.

separated by an angle of 15° on a dark field is fixated. Simultaneously all of the light is withdrawn from one of them and a large portion of it from the other. As a consequence, a general field movement is seen to progress from the region of the spot which completely disappeared to the region of the remaining dim spot. In this experiment we have the stimulus withdrawal conditions required for a test and find that movement starts from the point at which the most light is withdrawn and progresses from there to other regions. There is then nothing paradoxical in the expansion of a black object as it comes into existence nor does its expansion demonstrate a dependence upon the figure as such. In other words expansion and contraction have not been shown by the original *Lochversuch* to be exclusively figure properties.

Discussion

In the first place, it is to be understood that we are not attempting herein the same type of consideration of apparent movement as given in DeSilva's ('29) elaborate and careful study. In it emphasis was rightly made that to fully describe the conditions for movement one must include attitudinal and all other factors which comprise any *complete* experience. As a complement of such a study as well as of others, we have undertaken to outline some of the more or less 'sensory' conditions necessary for movement.

The fact that the essential pattern of gamma movement is clearly determined by the spatial discharge in the retina opens the way to a reconsideration of the relation between all forms of movement. It would appear that gamma movement is more closely similar to 'real' movement than to the other forms [4] though it seems probable that the same type of mechanism will account for all.

We may first consider gamma movement. In order to

[4] Various conditions other than those represented by a real moving object in the visual field external to the individual give rise to the experience of visual movement. These conditions have been partially and grossly classified. For instance a common case is *beta* movement which consists in seeing a single moving object when two stationary and separated objects are successively presented. These are the essential conditions for moving electric signs and the motion picture.

experience it, a spatial-temporal sequence in discharge of retinal elements is necessary, though there is a variety of ways of producing the sequence. The sequence may run a simple geometrical course on the retina or it may be complicated to the point of confusion for the experiencing observer. In any case the need of seeing a single moving object from a presentation of *discrete* stationary objects does not arise as in beta movement.

In real movement, spatial-temporal discharge in the retina is brought about by an actual moving region or regions of high or low stimulation across the retina. Consequently, it is obvious that gamma and real movement rely on the same mechanism.

Since the discovery that two objects separated in space and properly presented in time may give rise to the experience of a single moving object, constant conjecture has arisen as to where the neural continuum corresponding to the continuum in experience is brought about. For this the cortex has been favored. Aside from the cases in which alternate use of the two eyes produces a seen movement, it has not been shown that the synaptic layers in the retina or in the thalamus do not accomplish this fusion and send a unitary but properly differentiated pattern to the cortex to result in the seeing of a single object passing across the field of vision. That these centers should do this very thing is quite probable from what neurological evidence we have. As for example, it appears that two impulses starting out from different points on the retina at slightly different times do not remain out of tune all the way to the cortex (Bartley, 1935).

It is possible that at each synapse layer there is some degree of both convergence and divergence. Here parallel paths mutually affect each other to produce spatial summation. Here the effects of rapidly repeated discharge are summed to reduce latency (the intensity effect). Here succeeding impulses are facilitated even though these are arriving over paths *parallel* to those active immediately before, to produce a degree of synchronization. All of these activities are possible while retaining precise visual acuity when it is

supposed that parallel paths facilitate each other without producing actual discharge. On this basis one might expect that within certain space and time limits original groups of impulses elicited by stationary objects might coalesce in such a way as to similate the cortical input from a moving object in spite of the fact that in extreme cases the temporal interval between the presentation of two stationary objects to be seen as a moving one is longer than the latency of cortical response. This long temporal interval does not obviate the possibility that the parallel paths from the two spots interact below the cortex in the direction of producing a unitary or continuous discharge into the cortex where further change and elaboration must in all cases be admitted to take place but under limitations and in the manner imposed upon it by the nature of the input.

Gamma movement has been seen by those studying it to have some connection with the figure-ground phenomenon,[5] one of the 'higher mental processes,' [6] and has been taken as another example of them. The typical definition of gamma movement is given in terms of the figure-ground dichotomy placing movement in the figure. That movement *can* occur in the ground has been admitted upon several occasions in the literature, but nothing has been done toward understanding it, rather it has been almost totally slighted. Since gamma movement is the experience arising when the rate of intermittent stimulation used to produce both object and field flicker is reduced much below the fusion point, one would expect similar causal conditions for the two phenomena. It was shown that entoptic strary light institutes *flicker* in the field around the test-object (Bartley, in press). So it is to be expected that *movement* would not be confined to the test-

[5] Visual fields when not homogeneous can be said to have a dichotomous structurization, namely, the figure and the ground upon which the figure rests or is seen. Any departure from homogeneity in the field will result in the seeing of some part of it as 'thing-like' which at that moment is the figure. Figure and ground each have their own set of distinguishing properties.

[6] Experience has been traditionally divided into elemental and higher activities. The former include the so-called sensory processes such as brightness vision, the latter include the 'higher mental processes' such as reasoning, the attitudes, etc.

object (figure) alone as has been commonly implied, but under certain conditions involved the field (ground) as well.

Experiment confirms this and shows that there is nothing unique about the figure in producing movement; that in fact movement occurs when the visual field is not 'figured' in any way (case I).

As is the case with all other psychological phenomena, attitudinal factors emphasized and used as explanations by many persons are to be recognized in making a complete description, but the rôle which attitude plays is often misunderstood (Fry and Robertson, in press). It would seem from the experiments of these authors as well as from the present case we are faced with obtaining a better understanding of neurology before we shall know what to do with attitude in a causal system of behavior.

Summary

The present experiments consist in the manipulation of the relative amounts of stimulation given the various parts of the retina to show that perceived movement begins in the region of the visual field corresponding to the portion of the retina most intensely stimulated and proceeds to other parts of the visual field corresponding to less intensely stimulated parts, which is to be expected from the known shorter latency in response which follows strong stimulation than weak. The part played in the temporal-spatial succession in the discharge of the sense cells by the possible intrinsic latency differences of the rods and cones has not been possible to accurately determine on account of optical difficulties met with in attempting to evenly illuminate the entire retina since an evenly lighted visual field does not produce uniform retinal illumination.

In the light of the present demonstration, there seems to be no essential difference in the rôle played by the retina in cases of 'real' and gamma movement. On the other hand, if a neural continuum is needed to provide for the known experience continuum in cases in which two separated stationary spots are so presented as to be seen as a single moving spot

(beta movement) the locus of this continuum may necessarily be higher in the optic pathway than the retina. This is yet to be more fully understood by a series of experiments on temporal relationships.

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THE SPEARMAN–BROWN FORMULA IN ATTITUDE SCALE CONSTRUCTION

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Using the Purdue Personnel Rating Scale, Remmers [1] found that up to thirteen judges, the Spearman-Brown formula predicted the empirical reliability coefficient within two probable errors. Using groups of five, ten, fifteen, twenty, and thirty students to rate their instructors by means of this same rating scale, he found [2] that the reliabilities of the ratings agreed, within the errors of sampling, to those expected from an application of the Spearman-Brown prophecy formula. Kelley [3] showed that the reliability coefficients obtained from Gordon's weight judging data,[4] increased according to the prophecy formula. It seems, therefore, that the reliability coefficients of judges tends to increase according to the same law as those of lengthened tests.

In order to test this principle further, we sought to determine to what extent this same formula predicted the reliability coefficients of the sorters, or judges, used in the construction of social attitude scales.

Method.—We used 50 carefully selected and edited statements of opinion with regard to the question of German War Guilt. These statements were selected, upon the basis of expert opinion, so that they would form two parallel series of 25 statements each. Both preliminary and subsequent sorting showed that we were justified in doing this. We obtained the services of 22 graduate students and 28 undergraduate students, making a total of 50 sorters. They were asked to *sort* each group of 25

[1] Remmers, H. H., Shock, N. W., and Kelley, E. L., An empirical study of the validity of the Spearman-Brown formula as applied to the Purdue rating scale. *J. Educ. Psychol.*, 1927, **18**, 187–195.

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statements into eleven divisions according to the usual Thurstone technique.[5] After this was done, each sorter was given another pack of these same statements and asked to *rank* each statement from rank order 1 to rank order 25, according to the intensity of the bias expressed against Germany. The sorters were not aware that this ranking procedure was to follow the sorting procedure. Our purpose here was to determine whether ranking or sorting had any effect upon the accuracy of the predictions obtained from the Spearman-Brown formula.

For both sorting and ranking data, we obtained actual and predicted correlation coefficients. In order to test to what extent the Spearman-Brown formula as a curve fit these data, we applied the rectified form in each case. We tested further the adequacy of this law by using the differential form of the equation in order to determine if the differences between actual and predicted correlation coefficients were less than the maximum possible error.

Actual reliability coefficients were obtained by computing the correlations between the average ratings of each statement for paired groups of varying numbers of sorters. This gave us a series of computed correlation coefficients showing to what extent one group of sorters agreed with another group of the same number. We employed paired groups with 2, 3, 4, 5, 10, 15, 20 and 25 sorters in each group.

Predicted reliability coefficients were computed by means of the usual formula

$$r_p = \frac{nr_{11}}{1 + (n - 1)r_{11}},$$

where r_p stands for the predicted correlation coefficient, r_{11} stands for the correlation coefficient between single unitary elements (between one sorter and another sorter in our case), and n stands for the number of sorters in the group under consideration. The symbol r_c stands for a correlation coefficient computed from raw data which may be either mean sorting position or mean rank order.

In order to obtain this unit intercorrelation r_{11}, we took the average of twenty correlations based upon the data obtained from twenty pairs of sorters selected at random from the group of fifty.

Findings.—In Table I is summarized the correlations obtained from an analysis of the data obtained by having groups of judges of increasing number *sort* 25 statements of the German War Guilt scale.

From Table I we see a general tendency for the computed correlation coefficients to be somewhat higher than the predicted coefficients. The average difference between the two sets of correlations is not large, being different only in the third decimal place; the correspondence is therefore quite close. In the group of computed correlation coefficients there is one reversion, the value for 20 sorters being slightly lower

[5] Thurstone, L. L., and Chave, E. J. *The measurement of attitude*, pp. 31–2, Chicago: University of Chicago Press, 1929; see also A. C. Rosander, *The construction of social attitude scales*, unpublished Doctor's thesis, Department of Education, University of Chicago, 1933.

than that for 15 sorters. Otherwise there is a steady increase in both sets of values, n on the one hand, and r_p on the other.

These relationships are shown more clearly in Fig. 1 which is a graph of the data of Table I. The tendency of the formula to under-predict is readily seen. On the other hand, a slightly higher unit intercorrelation would have rectified this by moving the line of predicted correlation coefficients a little higher than it appears in Fig. 1. The two values which fell below the line of prediction, one of them being out of line of the trend expected, can be seen by inspection. The deviations

TABLE I

PREDICTED AND COMPUTED CORRELATIONS BETWEEN MEAN RATINGS OF 25 STATEMENTS OF GERMAN WAR GUILT SCALE FOR DIFFERENT PAIRED GROUPS OF SORTERS

Number of Sorters in Each Group	Number of r_c's Averaged	r_p	r_c	$(r_p - r_c)$
1	20		.8868	
2	12	.9400	.9379	+.0021
3	8	.9592	.9632	−.0040
4	6	.9691	.9701	−.0010
5	5	.9751	.9833	−.0082
10	5	.9874	.9888	−.0014
15	3	.9916	.9933	−.0017
20	1	.9937	.9927	+.0010
25	1	.9949	.9973	−.0024
	61		Mean	.0027

of the computed correlation coefficients from the line of prediction are not nearly so great in value as they appear due to the fineness of the vertical scale.

It will be seen that the curve rises rapidly up to a value of 5 sorters, and thereafter tapers off so that 20 and 25 sorters return reliability coefficients well up on the flat portion of the curve. Adding five sorters in this part of the curve does not add very much to the reliability of the sorting. According to these data, an actual empirical coefficient of .99 is obtained from 10 sorters, while a predicted coefficient of the same value is obtained from 14 sorters.

Another way of analyzing these data is to determine to what extent the Spearman-Brown formula is the best fitting curve through the data. In order to do this we converted the usual formula into a linear equation of the following form, wherein each symbol stands for the same quantity as before.

$$\frac{n}{r_c} = n + \left(\frac{1}{r_{11}} - 1\right)$$

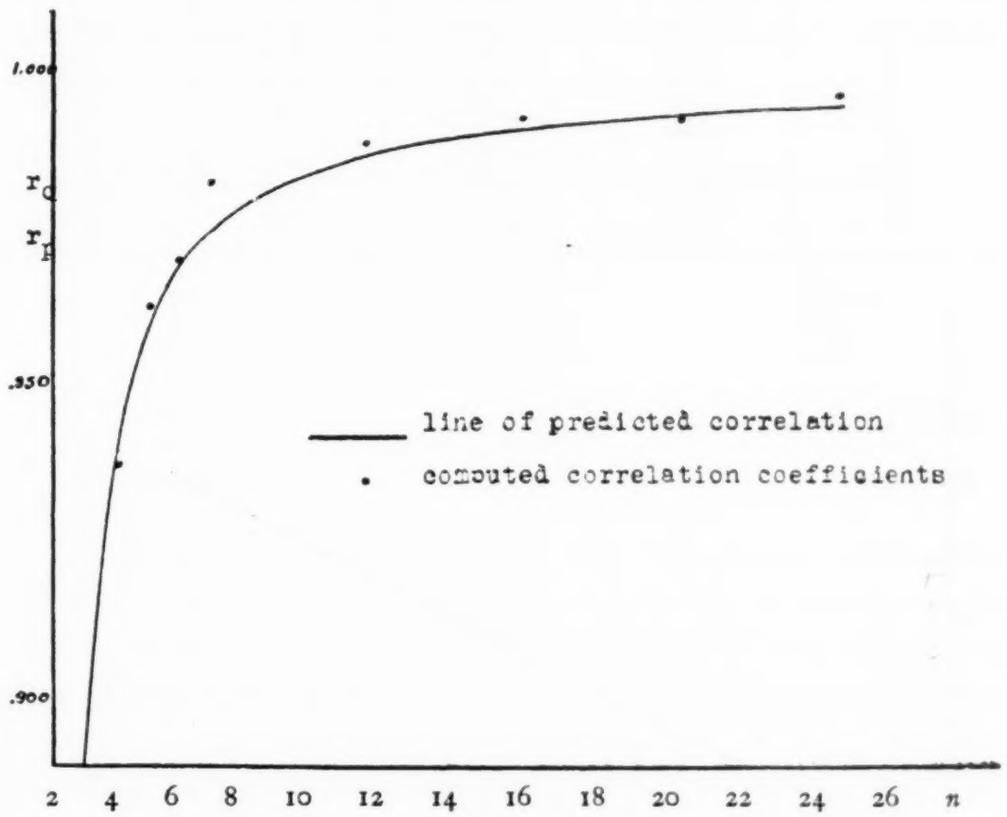

FIG. 1. Application of Spearman-Brown formula to data from sorted statements.

This means that if we plot values of n/r_c against values of n, we should obtain a linear relation if the data fit the Spearman-Brown law. The slope of this straight line will be unity, the y-intercept will be $[(1/r_{11}) - 1]$, and will always be positive under ordinary conditions. Table II gives the data necessary to verify this principle.

The data of Table II are shown graphically in Fig. 2. If we plot smoothed values of n/r_c, we shall have an exact linear relation throughout the entire range of n. This indi-

cates that the Spearman-Brown formula fits the data to a very high degree.

TABLE II

DATA FOR THE RECTIFICATION OF THE SPEARMAN-BROWN FORMULA CORRELATIONS FROM SORTED STATEMENTS

n	r_c	$\frac{n}{r_c}$	$\frac{n}{r_c}$ (smoothed)	$\Delta\frac{n}{r_c}$
1	.8868	1.127	1.1	
2	.9379	2.132	2.1	1.005
3	.9632	3.114	3.1	.982
4	.9701	4.123	4.1	1.009
5	.9833	5.085	5.1	.962
10	.9888	10.113	10.1	1.006
15	.9933	15.101	15.1	.997
20	.9927	20.147	20.1	1.009
25	.9973	25.068	25.1	.984

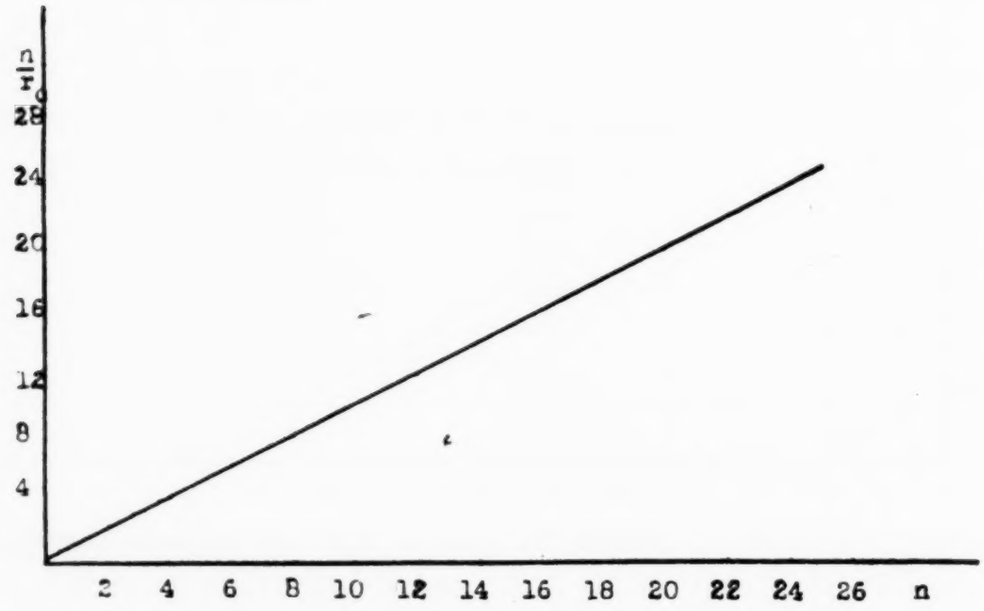

FIG. 2. Rectification of Spearman-Brown formula: sorted statements.

There is a further method of testing these data, a method making use of the differential familiar to students of the differential calculus. If we express the algebraic formula for the Spearman-Brown law in differential form we obtain

$$dR = \frac{n}{[1 + (n - 1)r]^2}\, dr,$$

where dR is the maximum error expected in the value of R, the predicted correlation coefficient, r is the unit intercorrelation and dr is its error of measurement, while n is the number of sorters in the group under consideration. From Table I we obtain the value of .887 for r, from repeated computations we estimated its error to be about .030. Using these values in the foregoing equation, and assigning different values to n, ranging from 2 to 25, we obtained values for dR. In Table III, we give these values of dR, together with the differences which we found to exist between r_c and r_p as given in Table I.

TABLE III

EXPECTED AND ACTUAL ERRORS IN RELIABILITY COEFFICIENTS

n	dR*	$(r_p - r_c)$
2	.0168	.0021
3	.0117	.0040
4	.0089	.0010
5	.0072	.0082
10	.0037	.0014
15	.0025	.0017
20	.0019	.0010
25	.0015	.0024

* r is .887; dr is .030.

In six of the values of Table III, the actual coefficients did not vary from the predicted values by as much as the maximum expected error, dR, while in two of the values but especially in the one where n equals 25, the difference between r_p and r_c is greater than the expected error in r_p. By and large this shows that the reliability coefficients computed from raw data tend to fall within the maximum error inherent in the predicted correlation coefficients.

The data from sorted statements have been discussed; we shall now turn to an analysis of the data obtained from ranked statements. The same sorters, the same statements, and the same grouping of sorters were used to obtain intercorrelations between mean rank orders as were used to obtain the correlations already discussed. Here as before, we are interested in determining to what extent one may predict the correlation between groups of sorters of an increasing number, given a mean unit intercorrelation with which to start.

Here as before we shall test the adequacy of the Spearman-Brown formula as a curve of fit. The basic data are given in Table IV.

The correlation coefficients were computed by the Spearman rank order formula with the Pearson correction being used to convert them into product moment correlation coefficients. Some experimentation with the computation of product moment coefficients direct from ranks themselves, showed that this method would lead to the same results.

Several differences stand out when the data of Table IV are compared with those of Table I. In the former table, the

TABLE IV

PREDICTED AND COMPUTED CORRELATIONS BETWEEN MEAN RANKINGS OF 25 GERMAN WAR GUILT STATEMENTS MADE BY PAIRED GROUPS OF SORTERS

n	Number of r's to get r_c	r_p	r_c	$(r_p - r_c)$
1	20		.9145	
2	12	.9553	.9522	+.0031
3	8	.9698	.9739	−.0041
4	6	.9771	.9766	+.0005
5	5	.9816	.9859	−.0043
10	5	.9907	.9898	+.0009
15	3	.9938	.9938	.0000
20	1	.9953	.9955	−.0002
25	1	.9963	.9960	+.0003
	61			Mean .0017

unit correlation is much higher being .9145 as compared with .8868 in the latter table. There is more fluctuation in the differences between predicted and empirical correlation coefficients, three being negative and four being positive. The mean of the differences between these two sets of correlations is .0017 in the present case as compared with the much higher value of .0027.

In Fig. 3 we present these data in graphic form. Comparison of Fig. 3 with Fig. 1 shows that the Spearman-Brown formula gives a better prediction and a closer prediction in the case of ranked statements than in the case of sorted statements. In Fig. 3 all the computed values, with the exception

of that for 5 sorters, fall very close to the curve of predicted values. In the present case as in the previous case, the reliability coefficient for 5 sorters deviated the most from what one would expect if increasing the number of sorters increased the reliability according to the Spearman-Brown formula.

Whereas the Spearman-Brown formula under-predicted for most of the coefficients obtained from sorted statements,

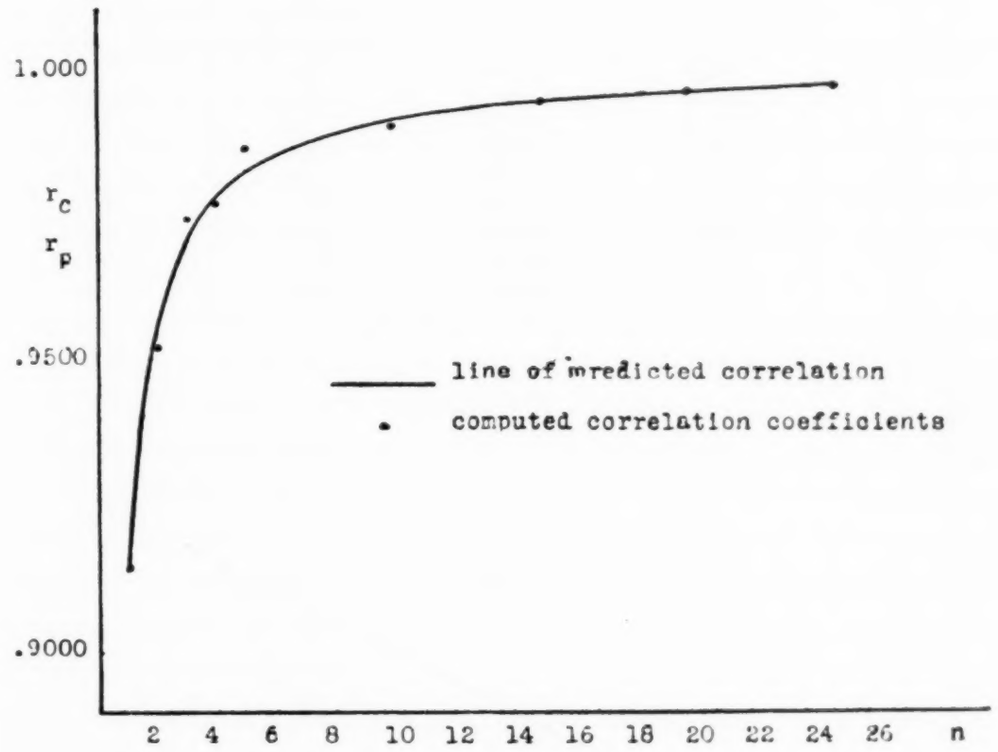

FIG. 3. The Spearman-Brown formula applied to ranked statements.

it was practically at par for those obtained from ranked data. In the present case, 10 sorters return a reliability coefficient of .99, both on the basis of computation from raw data, and on the basis of prediction from the formula.

In the present case there were no regressions in any of the computed values, each coefficient increasing as the number of sorters increased. This was not true with the data for sorted statements, there being one coefficient that was out of order.

We applied the rectification technique to these data also, with the results which are shown tabularly in Table V, and

graphically in Fig. 4. Here we found the linear relation to be just as exact as it was in the previous instance, the deviations from the straight line being too small to show on any ordinary graph paper.

TABLE V

DATA FOR THE RECTIFICATION OF THE SPEARMAN-BROWN FORMULA CORRELATIONS FROM RANKED STATEMENTS

n	r_c	$\frac{n}{r_c}$	$\frac{n}{r_c}$ (smoothed)	$\Delta\frac{n}{r_c}$
1	.9145	1.093	1.1	
2	.9522	2.100	2.1	1.007
3	.9739	3.080	3.1	.980
4	.9766	4.096	4.1	1.016
5	.9859	5.072	5.1	.976
10	.9898	10.103	10.1	1.006
15	.9938	15.093	15.1	.998
20	.9955	20.090	20.1	.999
25	.9960	25.100	25.1	1.002

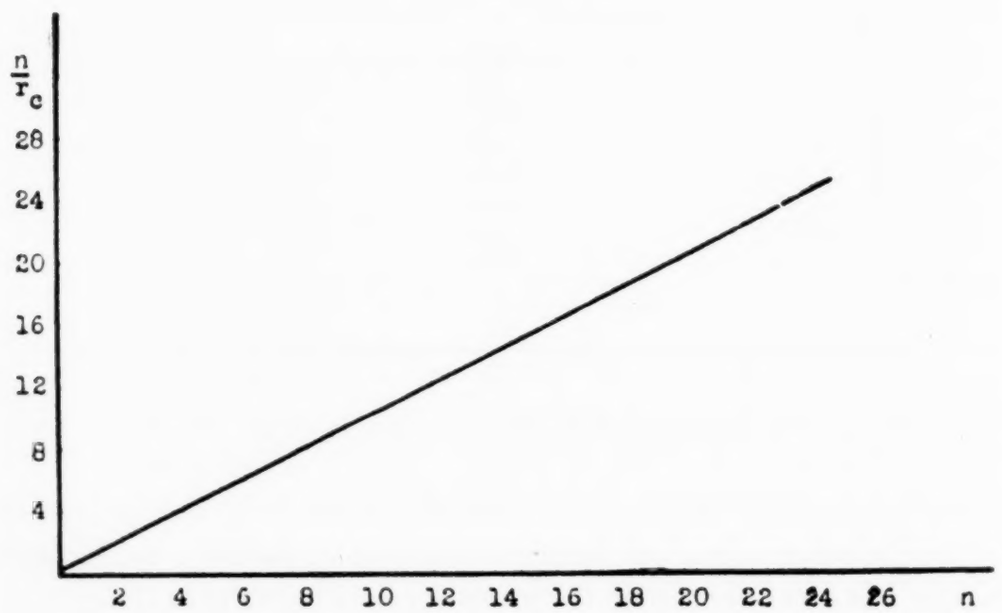

FIG. 4. Rectification of Spearman-Brown formula: ranked statements.

Conclusions.—We conclude that the type of sorter which we employed, including both undergraduate and graduate students from education, psychology, and the social sciences, does return reliability coefficients which increase according to the Spearman-Brown formula.

This increase in reliability coefficient as the number of sorters is increased is as marked with data from ranked statements as with data from sorted statements, the more usual method.

The formula tends to under-predict for data from sorted statements, and to be at par for data from ranked statements.

With the type of sorter which we employed, the flat portion of the curve is reached between the correlation values of .99 and 1.00, in which range we find the coefficients from 15 to 25 sorters.

The greatest additions to the value of the coefficient is made by adding the second, third, fourth, and fifth sorters. After that, if our data are correct, the addition of an extra sorter does not add so much to the value of the coefficient, and this addition grows less and less the farther up on the curve we go.

So far as the Spearman-Brown formula is concerned, reliability coefficients based upon the correlations between mean rank orders are as valid as those based upon the correlations between mean sorting position on an 11-division scale.

No doubt the tendency of sorters to follow the Spearman-Brown formula is contingent upon a series of fairly evenly graduated elements, which both preliminary and subsequent investigation showed we had in the two groups of 25 German war guilt statements.

Both the method of the differential, and of rectification, showed that our data were following rather closely the law expressed by the Spearman-Brown equation.

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THE INFLUENCE OF CERTAIN CONDITIONS PRIOR TO LEARNING UPON SUBSEQUENT RECALL

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The phenomenon of retroactive inhibition, or the detrimental influence of interpolated activities between learning and recall upon subsequent recall, is one that has been verified by a large number of investigators.[1] In an earlier investigation, one of the writers[2] obtained some evidence which supported the conclusion that certain activities introduced prior to learning may produce an inhibitive influence upon subsequent recall. More recently, some evidence has been cited which indicates that, under limiting conditions, certain activities prior to learning exert a detrimental influence upon learning efficiency.[3] Maslow,[4] using the method of memory span, in order to determine the influence of varying background conditions on learning efficiency, has presented evidence "as giving some slight support to the theory that similar conditions for learning and recall are more efficient than dissimilar conditions."

The present investigation was concerned with the dependence of recall upon certain conditions introduced prior to learning. Two types of learning material, monosyllabic words and poetry, were employed in two separate experiments.

In the first experiment, eighteen three- and four-letter monosyllabic words were used as the learning material. The words were typed on a sheet of paper and were placed face down before the subject. At the signal 'Go' the subject turned the sheet over and memorized as many of the words as was possible in the two minutes of time given to each subject. At the expiration of the allotted time for memorization, the

[1] For a selected bibliography see J. A. McGeoch, The psychology of human learning: a bibliography, *Psychol. Bull.*, 1933, **30**, 1–62.

[2] P. L. Whitely, The dependence of learning and recall upon prior intellectual activities, J. EXPER. PSYCH., 1927, **10**, 489–508.

[3] P. L. Whitely and Gerald Blankfort, The influence of certain prior conditions upon learning, J. EXPER. PSYCH., 1933, **16**, 843–853.

[4] A. H. Maslow, The effect of varying external conditions on learning, retention, and reproduction, J. EXPER. PSYCH., 1934, **17**, 36–47.

subject wrote on a blank sheet as many of the words as he could recall. Two minutes were given for the writing of the words in the immediate recall test as well as in the subsequent recall test. The subsequent recall test was given forty-eight hours later.

The thirty subjects, male students of Franklin and Marshall College, participating in this experiment, learned the material under three different conditions. In the first condition, no controlled activity, which we shall call the normal condition, preceded learning. In the second condition, learning was preceded by the memorizing of another eighteen-word list, which for convenience we may designate the similar condition. The third condition we have called dissimilar, and in this instance fifteen nonsense syllables were learned prior to the learning of the monosyllabics. Two minutes were given for the memorization of both types of prior lists, and the immediate recall tests were taken in the same manner as in the case of the other learning material. No controlled activity preceded the subsequent recall test.

Each subject learned a list under the three conditions mentioned above, and the order of learning for the various conditions was counterbalanced in order that each condition might have equal average position.

The results of the first experiment are presented in Table I. In the table are shown the mean number of words learned and

TABLE I

SHOWING THE RESULTS OF THE FIRST EXPERIMENT

	Conditions					
	Normal		Similar		Dissimilar	
	Learn	Recall	Learn	Recall	Learn	Recall
Mean no. correct	11.23	5.67	11.40	2.70	12.03	3.13
σ dis	2.28	3.08	2.76	1.96	2.34	2.32
σ M	.41	.56	.54	.34	.42	.42
Mean no. errors	.60	1.70	.70	2.60	.53	1.77
Percent recalled		50.74		20.76		26.04

recalled, the sigmas of the distribution, the sigmas of the mean, the average number of errors, and percentages of recall, for the three learning conditions. The mean number of words learned for the normal, similar, and dissimilar conditions are, respectively, 11.23, 11.40, and 12.03; whereas the recall scores for the same conditions are 5.67, 2.70, and 3.13. The percentages of recall in terms of the amount originally learned are 50.74, 20.76, and 26.04 for the three conditions, respectively.

These data indicate that the learning of either a similar list or a dissimilar list prior to memorization exerts a detrimental influence upon subsequent recall. A slightly greater harmful

influence is produced when the prior material is similar to the learning material. Also it will be observed from the table that more errors are made under the similar condition. This is undoubtedly due to a confusion of the two similar lists.

The differences in the learning scores for the three conditions do not appear to be significantly different, a result which is consistent with a previous investigation.[5] In this study it was ascertained that the arousal of certain apperceptive trends do not influence materially learning, but that they do influence inhibitively a later recall.

TABLE II

DIFFERENCE OF THE MEANS AND SIGMAS OF THE DIFFERENCE FOR THE DATA IN TABLE I

Conditions Compared	Diff. of M	σ Diff.	D.M./σ Diff.	Chances in 100
	Learning Scores			
Normal–similar	.17	.67	.25	60
Normal–dissimilar	.80	.58	1.38	92
Similar–dissimilar	.63	.68	.92	82
	Recall Scores			
Normal–similar	2.97	.65	4.57	100
Normal–dissimilar	2.54	.70	3.63	100
Similar–dissimilar	.43	.54	.79	79

Measures of reliability are shown in Table II. There are shown in the five successive columns, respectively, the conditions compared, the differences of the means, the sigmas of the difference, and the chances in 100 that the true difference is greater than zero, for both the learning and the recall scores. It will be observed that, in the case of the learning scores, the differences between the various comparisons do not show high reliability. However, in the recall scores, the differences between the normal and similar conditions and also between the normal and dissimilar conditions do meet the statistical criterion of three times the sigma of the difference.

[5] *Cf.* our second reference.

Incidentally, it may be stated that the learning scores for the prior lists have been computed, but are not presented. There is no evidence of an appreciable practice effect. In the case of the similar condition, the mean score for the prior lists was 11.36, as compared with 11.40 for the second lists. No statement can be made concerning the practice effect for the dissimilar condition, since the prior lists were nonsense syllables and are therefore not comparable with respect to difficulty. It hardly appears credible, however, that practice effects have vitiated the results in any way.

Second Experiment

The general procedure of the second experiment was similar to that of the first, save for the fact that poetry was used as learning material instead of the three- and four-letter words. Thus the memory material consisted of three stanzas of 'Gilpin's Ride.'[6] The poem consists of four lines to the stanza, and each learning unit was composed of three stanzas. Each subject participating in the experiment memorized under three experimental conditions. Consequently, there were three sets of three stanzas each.

The stanzas, typed on letter-size sheets of paper, were placed face down before the subject, and each of the twenty-four subjects cooperating in the experiment memorized the material under the three conditions, in a counterbalanced practice order, as indicated in the first experiment. The similar material used as a prior condition was composed of other stanzas of the same poem, which was learned in the same manner as the regular learning material. The dissimilar material, on the other hand, consisted of blank verse of about the same length as the three stanzas from the poem. Two and a half minutes were allowed for the learning of the stanzas, as well as for memorizing the blank verse.

At the expiration of the time given for the learning period, the subjects wrote on a blank sheet of paper as much of the material as they could recall. This was true for both the regular learning material and the learning material which served as a prior condition. A subsequent recall test of the major, but not of the prior lists, was called for forty-eight hours later. The learning and recall scores were computed by determining the number of lines reinstated at the time of the immediate and subsequent recall tests. Account was also taken of four different kinds of errors, namely, omissions, misplacements, additions, and substitutions. Still another type of error was noted and that was that in some of the recalls lines of stanzas learned under a previous condition were reinstated. These errors are not shown in the table, but will be remarked in connection with a statement of the results.

The data for the learning and for the recall scores are presented in Tables III and IV, respectively. The average number of lines learned for the normal, similar, and dissimilar

[6] To be found in 'Notes for Instructors' to accompany *Experiments in Psychology* by Foster, W. S., and Tinker, M. Pp. 22–24.

TABLE III

LEARNING OF POETRY
Errors

	No. Lines	Omis.	Misp.	Add.	Subst.	Total
	Normal					
Mean.....	8.08	1.71	1.29	1.88	5.41	10.24
σ dis.....	2.51					
σ M.....	.51					
	Similar					
Mean.....	8.58	1.88	.83	1.46	5.04	9.17
σ dis.....	2.93					
σ M.....	.59					
	Dissimilar					
Mean.....	7.54	1.96	.58	1.04	5.38	8.96
σ dis.....	3.42					
σ M.....	.69					

conditions are 8.08, 8.58, and 7.54, respectively. It is interesting to note that slightly fewer lines are learned when learning is preceded by dissimilar material. This difference, however, is probably not significant and is due to chance factors, since the difference is not a truly reliable one. The error scores appear to indicate no significant trend, as the differences are too small to be reliable.

From Table IV it will be observed that the average number of lines recalled for the respective conditions, indicated in the previous paragraph, are 6.08, 3.92, and 3.54. In general, the results here are congruous with those of the first experiment. More material is recalled when no controlled condition preceded learning than when learning was preceded by the learning of other material, similar or dissimilar to the regular learning material. In both absolute terms and in terms of the percentage recalled of the amount learned, less is recalled under the dissimilar condition. In the first experiment, the amount retained in relation to the amount learned was slightly greater for the dissimilar condition than for the similar condi-

tion. So small are these differences, however, that they cannot be stressed.

TABLE IV

RECALL OF POETRY
Errors

	No. Lines	Omis.	Misp.	Add.	Subst.	Total
	Normal					
Mean	6.08	3.54	1.46	2.79	7.87	15.66
σ dis.	3.22					
σ M.	.66					
Percent R.	75.26					
	Similar					
Mean	3.92	1.33	.91	1.25	4.04	7.54
σ dis.	3.18					
σ M.	.65					
Percent R.	45.64					
	Dissimilar					
Mean	3.54	1.50	1.04	1.00	4.83	8.37
σ dis.	3.33					
σ M.	.68					
Percent R.	41.43					

The average number of errors is greater for the normal condition than for the other two conditions. However, the average number of errors in relation to the amount retained, makes the difference slight and probably lacking in significance. Albeit, some significance may be attached to the type of error remarked in a preceding paragraph. The reference is to lines that were reinstated that belonged to a previous learning. Under the similar condition, thirteen such lines for all the subjects were reinstated, whereas only four and five lines for the normal and dissimilar conditions, respectively, were revived. This fact would seem to indicate that greater confusion obtains when the prior learning material is similar to the other memory material.

The reliability of the data of Tables III and IV are presented in Table V. It is readily observed that the differences

TABLE V

DIFFERENCES OF MEANS AND SIGMAS OF THE DIFFERENCE FOR THE DATA IN TABLES III AND IV

Conditions Compared	Diff. of M	σ Diff.	D.M./σ Diff.	Chances in 100
	Learning			
Normal–similar	.50	.78	.64	74
Normal–dissimilar	.54	.86	.63	74
Similar–dissimilar	1.04	.91	1.14	87
	Recall			
Normal–similar	2.06	.93	2.21	99
Normal–dissimilar	2.44	.95	2.57	99
Similar–dissimilar	.38	.94	.40	65

between the normal and similar conditions and normal and dissimilar conditions for recall are those that approach satisfactory statistical reliability.

DISCUSSION OF RESULTS

There is general agreement in the results of these two experiments. With both types of learning material—three- and four-letter words and poetry—the normal condition is superior for subsequent recall to either of the other two conditions, where the conditions prior to learning consisted of the learning of other similar material or of material dissimilar in character. In the work on retroactive inhibition, a considerable body of results indicates that similar material exerts the greatest detrimental effect. No positive statements in this respect may be made from the results herein reported. The differences between the similar and dissimilar conditions are slight.

However, the significant fact to be noted is the inhibitive influence of a condition introduced prior to learning upon a subsequent recall, and thus the implication that any set-up involving two lists in sequence introduces a two-way inhibition. Such an inhibitive influence as is reported in this

paper has not been very generally noted. The term *proactive inhibition* may be employed to describe the phenomenon under consideration to differentiate it from retroactive inhibition.

Not all of the theoretical issues relevant to the phenomenon of retroactive inhibition have thus far been resolved. However, the theories of perseveration and transfer have been invoked to explain how retroaction operates. While the experimental evidence is not entirely conclusive, a majority of experimental findings may probably best be explained in terms of a transfer theory. Obviously the results reported in this paper may be more easily subsumed under the principle of transfer than under that of perseveration.[7]

Summary and Conclusions

This study was concerned with the influence of certain conditions introduced prior to learning upon subsequent recall. The results of two different experiments were reported, using two kinds of learning material. In the first experiment, monosyllabics were used for the memory material, whereas poetry was employed in the second experiment. The prior conditions consisted of the learning of other similar or dissimilar material to the regular memory material. We may conclude that:

1. The results of the two experiments are in essential agreement.
2. The recall scores are best when learning occurred under the normal condition, or no prior activity preceding learning.
3. The introduction of activities, both similar and dissimilar to the memory material, exerts an inhibitive influence upon subsequent recall.
4. Somewhat higher reliability was obtained for the differences of the recall scores of the words than for the poetry.

[7] For a discussion of the theories of retroaction *cf.* J. A. McGeoch, The influence of four different interpolated activities upon retention, J. Exper. Psych., 1931, 14, 400–413.

5. In the recall of poetry, there was evidence of greater confusion when the prior condition consisted of similar material, as indicated by the greater tendency to reinstate lines of stanzas previously learned.

6. The theoretical conclusion was that the results may be better subsumed under the principle of transfer than under the principle of perseveration.

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THE EFFECT OF INTERFIXATION DISTANCE ON BINOCULAR FIXATION MOVEMENTS

BY BRANT CLARK

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Introduction

The problem of ocular fixation has been studied by numerous investigators using different photographic techniques. McAllister (**6**) found that the two eyes do not fix a point in the same manner and that the method of fixation is different for different fixation objects and different surroundings. Dodge (**4**) using another method also found marked irregularities during fixation and showed that there is a clearing up period during the early part of the fixation. Dearborn (**3**) studied two subjects and found that when the eyes changed their fixation between two points 40° apart, the initial fixation was not accurate and that another saccadic movement occurred to correct the error of fixation. A similar thing was found by Miles (**7**) and an examination of McAllister's charts (**6**) also shows this to be the case with part of his subjects at least. These studies, however, were limited either to a small number of subjects, photographic records of but one eye, or one interfixation distance.

It was the purpose of the present investigation to attack the problem using a method of eye movement photography which would record binocular vertical and horizontal movements, and to study a larger number of subjects and four interfixation distances for each of two different fixation objects.

Apparatus and Procedure

The eye movements of the subjects were photographed using the camera previously described by Clark (**1**). The records showed binocular horizontal and vertical movements under relatively high magnification. The fixation objects were mounted on heavy cardboard just under the photographic lenses at a distance of 30 cm from the subject and were illuminated by a 60 watt lamp.

Two types of fixation objects were used, words and dots. The dots were black on white cardboard and subtended an angle of approximately 18′ at the subjects' eyes. The following eight words were also used for four interfixation distances: 1. have-save, 2. atom-they, 3. know-gone, 4. kind-been. These words were printed in 10 point Caslon and subtended an angle of approximately 1° at the subjects' eyes. The longest interfixation distance was 26.42°, the smallest 8.57°. These dimensions included the usual limits for the length of lines used in reading material (50–150 mm). The other distances are listed in Table I.

TABLE I

A Comparison of the Characteristics of the Fixation Movements for Different Interfixation Distances

Interfixation Distance	Divergence Movements		Corrective Movements in Minutes	Frequency of Adjustments in Percent	
	Magnitude in Minutes	Time in 1/25 Secs.		Divergence	Corrective
	Words				
1. 26.42°	84.5 ± 22.5	5.62 ± 0.71	65.7 ± 39.5	96.5	66.8
2. 20.60°	67.1 ± 28.2	5.61 ± 0.92	75.3 ± 37.5	97.5	76.1
3. 14.32°	42.3 ± 22.3	5.92 ± 0.72	29.1 ± 31.9	85.0	51.4
4. 8.61°	28.7 ± 12.3	5.65 ± 0.74	17.5 ± 21.5	78.0	37.6
	Dots				
1. 24.60°	71.9 ± 22.5	5.52 ± 0.92	68.1 ± 40.1	95.0	71.4
2. 17.17°	66.1 ± 19.4	5.66 ± 0.85	52.1 ± 39.4	97.5	67.3
3. 13.50°	42.3 ± 18.5	5.48 ± 0.78	31.6 ± 33.4	90.0	43.7
4. 8.57°	23.3 ± 10.6	5.71 ± 0.76	16.0 ± 18.3	68.0	26.9

The subjects changed their fixation between the points keeping time with a metronome beating 90 times per minute. After several practice trials during which the subject's eyes were observed directly, he was placed in position and records were taken for two interfixation distances. Four separate exposures were taken for each subject, and a rest period was allowed between trials. The whole procedure lasted approximately 20 minutes, and in this time about 10 movements were made between the fixation points for each interfixation distance. The order of the trials was changed at random from subject to subject. A total of 1124 interfixation movements used in the final tabulation was obtained from 11 psychology students in the university.

Results

The records were examined to determine any differences or similarities in the behavior of the eyes in the various situations. In all cases the records were measured directly with a millimeter rule, or the distance was determined by the use of dividers and a millimeter rule. The latter method was always used in measuring the convergence or divergence movements. In each case the measurement was made to

the nearest 1/2 mm, and any deviation less than this was considered as a part of the fixation. In other words the records showed ocular rotations as small as 24′.

Corrective Movements.—As has been shown above Miles (**7**), Dearborn (**3**), and McAllister (**6**) found in studying interfixation movements that, after a brief fixation which involved a clearing up period, there was a short saccadic movement to correct the fixation. These movements are termed in this paper, 'corrective movements.' The records were examined to determine the characteristics of these movements.

The results are summarized in Table I. It can be seen that within the limits of this study there is practically a linear relationship between the size of the corrective movement and the interfixation distance. However, if Dearborn's results (**3**) for 40° can be compared with these data, it would appear that these movements would not increase as rapidly beyond 30°. In a large majority of the cases (95.5 percent), the corrective movements occurred because the first fixation fell short of the mark. Some of these corrective movements were as large as 4.9°, *i.e.* nearly 5 times the length of the word. In several instances the first fixation was beyond the fixation point, and these corrective movements were as large as 3.2°.

The average corrective movement for the largest interfixation distance was found to be 68.1 ± 40.1′ and for the smallest 16.0 ± 18.3′. There was no consistent difference shown in the fixation of the words and the dots. The reliability of the difference between the largest and smallest interfixation distances was determined and found to be quite high, as shown by Table II, in spite of the high variability.

TABLE II

	Divergence Movements		Corrective Movements	
	D_{1-4}	D/P.E. Diff.	D_{1-4}	D/P.E. Diff.
Words.....	55.8′	21.5	48.2′	15.9
Dots.....	48.6′	16.7	52.1′	12.2

Table showing the reliability of the difference between the largest and the smallest fixation adjustments.

The percent of the total number of interfixation movements in which corrective adjustments occurred was also determined. These results are also tabulated in Table I and show that the number of corrective movements (greater than 24′) decreases with the interfixation distance. No difference was found in the movement of the eyes from right to left and from left to right. No attempt was made to determine any time differences in the saccadic movements because they were too rapid to be determined accurately within the limits of the camera (1/25 sec.).

Divergence Movements.—The photographic records were also examined to determine the characteristics of the binocular adjustments made during the initial part of the fixation. It was found that of the 1124 adaptive movements only 3 were convergence adjustments, and these were found in the same subject in one series of interfixation movements. In other words, in the large majority of cases, the eyes over converged in moving from one point to another. This caused a divergence adjustment during the fixation.

The magnitude and time of these movements was determined, and the results are shown in Table I. It was found that, within the limits of the experimental data, the divergence movements increased with the interfixation distance. This increase in the size of the divergence adjustments was, of course, due to the fact that as the interfixation distance increased, the over convergence increased. However, the time required to complete these divergence movements bore no relation to the size of the movement. An examination of Table I also shows that these divergence movements occurred more frequently when the interfixation distance was relatively large, and that there was no consistent difference in the fixation of the different objects.

The average magnitude of the divergence movements fixing words at the largest interfixation distance was found to be $84.5 \pm 22.5'$ and $28.7 \pm 12.3'$ for the smallest. The reliability of the difference between these averages was found to be quite high as shown by Table II although the variability was large.

It is interesting to note that there is a marked difference between these findings and those of Clark (**2**) in a reading situation. Both the magnitude and time of the divergence movements in this experiment are over twice as large as those for the same length of line and size of type in a simple reading situation. This is probably due to the fact that the two processes are fundamentally different. In this study, the movement is a voluntary change of fixation at a given signal while in reading the movement is less voluntary in nature. The former situation probably has a tendency to cause a more positive movement (convergence) during the return sweep. This in turn would require greater divergence adjustments. Part of the difference is also probably due to the fact that the eyes in reading do not have to fix the extreme end of the line and do not have to be as accurate as when they are fixing a single word.

Vertical Movements.—The vertical component of the movement during the return sweep was also measured. It was found, as has been previously been found by Schmidt (**8**) and Clark (**2**), that the eyes moved up during the saccadic movement between the two points. Vertical movements greater than 24′ occurred during 99.1 percent of these movements. In other words, the eyes moved up and converged during the return sweep. The magnitude and time of these movements are tabulated in Table III. There was an increase

TABLE III

Interfixation Distance	Vertical Movement	Time in 1/25 Secs.
1	75.0 ± 25.4′	2.35 ± 0.88
2	69.0 ± 20.9′	2.65 ± 0.72
3	59.4 ± 22.7′	2.53 ± 0.93
4	51.6 ± 20.9′	2.17 ± 0.79

The average vertical component of the fusion movements (words only).

in the magnitude of the extent of the corrective adjustment as the interfixation distance increased, but the time did not vary regularly. There was also high variability in the time and the extent of the movement. The average vertical corrective movement for the largest interfixation distance (75.0 ± 25.4′) was slightly smaller than that found by Clark

(2) under similar conditions in reading. Vertical corrective movements as large as 3.6° occurred and lasted as long as 6/25 second.

The time required to complete the vertical component of the corrective adjustment was less than half of that for the horizontal divergence component, *i.e.* on the average, during the fixation pause, the eyes moved down and diverged for about 1/10 second; at the end of this time the vertical movement ceased and the eyes continued to diverge for approximately 3/25 second more, at which time the divergence movement ended. After this time irregular fixation movements occurred. The clearing up process was probably not completed until after the divergence movement ended.

In general, the results show a marked variability not only in the action of one eye as compared to the other in any given movement and in successive movements, but also in the action of each eye itself on repetition of the same movements. Although on the average the corrective adjustments are larger for the larger interfixation distances, relatively large corrective adjustments also occur at times, and for no apparent reason, after the small interfixation movements. There are also wide differences between subjects.

The results as a whole lead to the conclusion that the eyes fix words in a similar manner to the way they fix dots, *i.e.* the eyes fix the word as a single unit under the conditions of this experiment. On the surface, these results may seem to differ with the findings of McAllister (**6**) who found differences in the methods of fixation for different fixation objects. However, his fixation objects included both vertical and horizontal lines of considerable size and which presented quite a different situation.

These results also give some evidence in regard to the question which has been raised by Gates (**5**), namely, "What do we know about the optimum lengths of lines in reading?" Gates points out that there is little experimental evidence at hand. The results of this study would seem to give evidence in favor of shorter lines in reading because they tend to show that the shorter the interfixation distances the smaller is the

number and size of the vertical and horizontal corrective adjustments during the first fixation pause. When the initial regressions ('corrective movements') are taken into account, there would be little difference in the actual number of fixations in spite of the increase in the number of return sweeps from the end of one line to the beginning of the next, and the fatiguing convergence and divergence movements would be reduced in number and extent. However, as has been shown above, the results of this experiment cannot be applied directly to reading situations for the reasons mentioned.

Summary and Conclusions

Using the method of eye movement photography, 1124 interfixation movements of 11 subjects were studied for two fixation objects. Four interfixation distances were used for each object, and the interfixation distances varied between 8.57° and 26.42°. An examination of the eye movement records leads to the following conclusions:

1. There is an increase in the size of the corrective movements made by the eyes as the interfixation distance increases within the limits of this study.
2. The magnitude of the divergence adjustments during fixation also increases directly as the interfixation distance increases.
3. The corrective adjustments occur more frequently for larger interfixation distances.
4. During the interfixation movement, the eyes move up and converge. The magnitude of the vertical component of the movement increases with the interfixation distance.
5. No significant difference was shown in the time required to complete the divergence movements after different interfixation movements, but the average vertical component of the movement was completed in less than one-half of the time required to complete the average horizontal divergence component.
6. There was marked variability in the behavior of the eyes for all of the factors examined.

7. There was no difference found in the way the eyes fixed words and dots. The words seemed to be fixed as simple units.

8. The results give evidence in favor of short lines as compared to long lines for reading material.

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EFFECT OF FATIGUE ON THE PRIORITY OF BILATERAL MOVEMENTS OF THE FINGERS

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The measurement of the laterality of function of the various peripheral organs is a relatively simple task. In the way the individual uses his hands, for example, certain specific activities are found to be consistently right-handed; others are, with equal consistency, left-handed; and still others are ambidextrous. Similar asymmetries may be established for specific functions of the eyes, the ears, the feet, etc. In the case of the hands, at least, the greater proportion of specific activities is customarily performed by one or the other hand, that member being called the 'preferred' hand.

Central Laterality.—The existence of this preference has led some to believe that there is a factor of 'central laterality' which determines the asymmetries of peripheral functioning. "We are right-handed," said Le Conte, "because we are left-brained" (**5**). Such a factor of 'central laterality,' sometimes called 'cerebral dominance,' would suppose a consistent rightness or leftness of functioning of the organism as a whole, not merely of the preferential use of the hands. The fact is, however, that this has not been found. Correlations between specific manual and specific ocular functions, for example, have not been sufficient to indicate a consistent laterality. Neither visual acuity nor auditory acuity have been found to be related to handedness.

In the case of manual activities it is obvious that social factors, customs, conveniences, etc., operate to influence the use of the hands. Evidence for or against central laterality has, therefore, been sought in functions in which social influences are not so obvious or in those in which neurological factors may be measured more directly. In the former group

are the tests of mirror drawing, of simultaneous writing with the two hands, as well as other tests. In such measures it seems evident that direct social influences, such as positive or negative transfer from the use of the hands in writing, help to determine the laterality of the function. In the group of tests intended to measure neurological laterality more directly have been chronaxie of bilaterally paired muscles, action currents, and the leading hand in attempted simultaneous movements of the two hands.

Leading Hand.—A number of studies of the leading hand have agreed in showing a consistent prior movement by the 'non-preferred' hand. Travis and Herren (**8**), Travis and Bryngelson,[1] and Jasper (**4**) found this true in antitropic movements of the arms. Metfessel and Warren (**6**), using a photographic technique, found it was also true of attempted simultaneous movements of the fingers. Further study has supported the conclusion that the hand not used in writing consistently moves earlier when it is intended that the two hands shall move simultaneously.

Jasper (**3**) related this precedence to central laterality by explaining it on the basis of chronaxie. A characteristic of the dominant neurological organization was held to be its shorter chronaxie. The slower response of the 'preferred' hand was due to the fact, which Monnier and Jasper (**7**) reported, that the shorter the chronaxie, the slower was the rate of propagation of the nerve impulse. Hence, in spite of the longer chronaxie there would be an earlier contraction of the muscles of the non-preferred hand because neural impulses would travel more rapidly to them.

Over-compensation.—Metfessel and Warren (**6**), on the other hand, believed that the prior movements of the 'non-preferred' hand were due to a form of over-compensation by that hand. In the attempts to move the two hands at the same time an allowance may be made for the perceived inefficiency of the non-preferred hand. This allowance may take the form of greater attention to, or greater effort on the part of, the inferior member. If a sufficient allowance is

[1] Research reported by Jasper (**4**), p. 85.

made the movements may differ only slightly and in a chance order. If too great allowance is made the non-preferred hand will consistently precede.

Further research on the priority of bilateral movements of the fingers (9) has supported the conclusion that over-compensation is involved. Not only did the forefinger of the hand not used in writing tend to precede the forefinger of the writing hand in attempts at simultaneous movements, but if the little finger of the non-preferred hand were used with the forefinger of the preferred hand the tendency became more pronounced. In the comparison of the forefingers, the hand not used in writing moved earlier consistently for 57.9 percent of the subjects; the writing hand moved first in 25.0 percent, and for 17.1 percent neither hand consistently preceded.

The little finger of the non-preferred hand consistently preceded the forefinger of the preferred hand in 87.5 percent of the subjects; while the opposite was true in 7.5 percent and neither finger led consistently in 5.0 percent of the cases.

When the little finger of the writing hand was compared with the forefinger of the non-preferred hand, the little finger was found to move earlier consistently. If attempts were made to move the little finger and the forefinger of either hand simultaneously the little finger preceded the forefinger in a significantly greater number of the cases. In each case there were prior movements by the less-used member of the pair of fingers. It is difficult to reconcile such results with an attempt to explain prior movements on the basis of central laterality. Rather they seem to indicate a tendency to allow for an inferiority either actual or subjective.

Exercise and Latent Time.—Another approach to the problem was to establish a physiological inferiority of one hand by experimental means, and to determine which hand led under such circumstances. The physiological effect of fatigue offered a method of accomplishing this end. One result of violent exercise of a muscle is an increase in the latent time of that muscle. This has been demonstrated frequently in excised muscle and recently has been shown in intact muscle as well. Affre (1) applied electrical stimuli

directly to the gastrocnemius muscle of man and found that the latent time was shortened after a small amount of exercise and increased after strenuous exercise. Brown and Tuttle (2) reported that fatigue resulted in increased reaction time, although a small amount of exercise caused decreased reaction time.

Procedure.—The procedure of the present study was as follows. A total of 48 subjects were tested to determine the leading hand (1) after violent exercise of the right forefinger, (2) after violent exercise of the left forefinger, and (3) under control conditions in which neither hand was specifically exercised before the test. At least 24 hours elapsed after one hand had been exercised and the test had been made, before the next test.

Apparatus used to exercise the fingers consisted of a key, similar to a large telegraph key, securely mounted so that in pressing it down the subject would squeeze it between the finger and the heel of the hand. Resistance to the pressure was furnished by a coil spring. A pressure on the key of 5 kilograms was required to completely compress the spring. Each subject was instructed to press the key repeatedly as hard and as fast as possible for a period of 30 seconds for the non-preferred hand and for 45 seconds for the preferred hand. It was observed that the exertions of the subjects produced little depression of the key by the end of the period of exercise, indicating that considerable fatigue had been produced. Subjective reports from the subjects also indicated that fatigue had resulted.

Immediately after exercising the forefinger of one hand, the subject was asked to press two telegraph keys simultaneously, one with the forefinger of each hand. The keys were mounted on the sides of heavy wooden blocks, in such a way that the movement of the fingers toward the palms of the hands would depress the key. Both keys were of the 'break' type and opened the circuits in which they were placed as soon as they were pressed. The electrical circuit was arranged to indicate which key had been pressed first by the flash of a "neon" glow lamp. If one key were pressed first the lamp would flash; if the other key moved first the lamp remained unlighted. Absolute simultaneity of movement is practically impossible and a variation as small as .00001 second favoring the first key would cause the lamp to flash. As a check on the balance of the apparatus the two keys were placed in one position for one half of the trials and reversed for the other half. The approximately equal proportion favoring one hand indicated the accuracy of the device.

The subject was required to press the keys rhythmically at the rate of 45 times per minute. The experimenter counted the number of flashes of the neon lamp and the number of times the keys were pressed in which the lamp did not flash. At least 100 trials were recorded for each subject and for each situation.

Results.—The consistency of the leading finger was determined in terms of the percentage of prior movements by the right or left hand. A percentage was considered significant if it differed from 50 percent by at least 3 times the standard error of the percentage.

In 67 of the 96 tests in which one or the other finger was

fatigued one finger led consistently. In 79.2 percent of the consistent leads, or 53 subjects, the finger which had been strenuously exercised just before the test moved first. The median individual tested after exercising the left forefinger resulted in 70.6 percent leads by that finger. After exercising the right forefinger, the median score was 69.3 percent leads by the right hand.

In 14 tests the hand which had been fatigued was consistently slower in its relative response. Of this group, 12 were by individuals who led with the preferred hand under control conditions; indicating perhaps, the influence of a greater or smaller tendency to allow for the perceived inferiority. Of the subjects who, under control conditions, led consistently with the non-preferred hand, only 7.1 percent of the tests indicated consistent leads by the hand not experimentally fatigued; while of the group which led with the preferred hand, 23.6 percent of the experimental leads were by the unexercised hand.

Conclusions.—In attempts to move the fingers of the right and left hands voluntarily at the same time there is a consistent tendency for the hand not used in writing to precede. That this fact is due to a form of over-compensation is indicated by:

(1) The precedence of the little finger over the forefinger, and
(2) The precedence of the finger experimentally fatigued by strenuous exercise over the non-fatigued one.

The existence of a tendency to allow for perceived inferiority makes the determination of the leading hand, when the subject attempts to move both hands simultaneously, invalid as an indication of 'central laterality.' It also suggests the questionableness of any test of 'native handedness' which may be influenced, either directly or indirectly, by the way the hands are habitually used.

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THE TIME RELATIONS OF THE EVENTS IN QUICK VOLUNTARY MOVEMENTS

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In previous experiments with quick voluntary reactions we have found it difficult to correlate certain of the results with any other internal factors, and it seemed, therefore, that a more careful study of these reactions was needed. Though this present study does not greatly simplify the matter, the results may be of value because of their relative isolation. As has been shown in a previous paper,[1] the text-book account of antagonistic muscle action is somewhat over-simplified. It appears that in most voluntary reactions the antagonistic muscles are both found to be in contraction early in the reaction. At low film speeds this reaction in both muscles appears to start simultaneously, but with faster speeds this apparent simultaneity disappears. The primary aim of the present experiment, therefore, will be to measure this difference and to discover any relations that may exist.

The apparatus for recording action potentials is described in detail in the above paper. Briefly, it consists of two parts—recording apparatus and electrodes. The former is now more or less conventionalized and will need no complete description. We used a Westinghouse oscillograph and four amplifiers of which two were usually used alone. These amplifiers were kept roughly equivalent in their amplification and were practically matched. They were shielded from each other, and were usually worked at a sensitivity such that 20 micro-volts R. M. S. input at 100 cycles gave a full wave deflection of one centimeter on the output. The electrodes were of the 'thumb tack' variety. These are made by projecting the point of a cutting needle somewhat beyond a one centimeter square of monel metal in such a manner that the point of each electrode, when placed on the skin, will penetrate to the derma. Two of these were used on each muscle, approximately 3 centimeters apart. Preliminary experiments indicated that this arrangement satisfactorily isolated one muscle from another. It should be remembered that there is always some doubt of this point, and all we can finally say is that there was every indication that practically no carry over from one muscle to the other obtains. The reaction employed for these experiments was the sudden flexion or extension of the forearm about the elbow joint with the arm supported in a nearly horizontal position. The muscles used, therefore, were the

[1] J. Exper. Psychol., 1935, **18**, 285–298.

biceps and triceps brachii—usually of the right arm. The subject was instructed to flex or extend the forearm as quickly as possible after the presentation of the stimulus. He was generally allowed to practice for a number of reactions; and it was not announced to him which of his reactions was photographed. For most of the reactions extension was used, because this movement is more definitely dependent upon a single muscle, the triceps brachii, than is flexion upon the biceps. The stimulus was the automatic lighting of a neon lamp in the subject's field of vision. The warning was usually given verbally, though for part of the experiment an automatic warning signal was used. In some other cases, a loud scraping sound was maintained throughout the warning period to mask extraneous clicks from the apparatus. For most of the records the time between the warning and the stimulus was not held constant but averaged approximately two seconds. The forearm was supported upon an arm rest which allowed free rotation in a horizontal plane, and this movement of the arm rest was recorded on the film. The film was run at a speed such that one sigma on the time line, vibrating at .500 per second, occupied approximately one millimeter. For most of the records, one of the experimenters served as subject, but similar records were obtained from six other individuals as a check upon the findings.

Figure 1 is a sample record demonstrating the phenomena that will be discussed. This record shows the appearance of

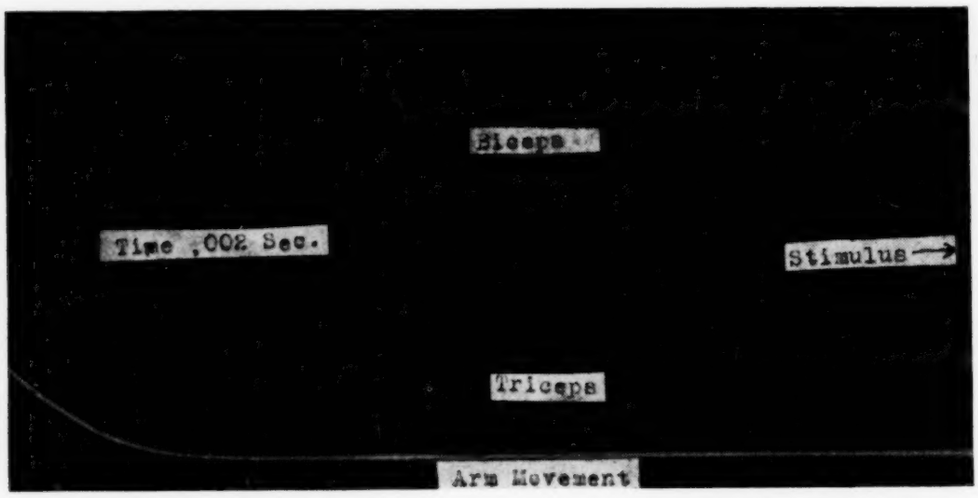

FIG. 1. A sample record showing the time of initiation of activity in the muscles and the inhibition of activity in both muscles before the reaction.

contraction in both muscles and the movement of the forearm. The two muscles did not initiate their activities simultaneously, the intervening period varying from 0 to 29 sigma. Most records show this interval to be very near to 7 sigma. We have attempted to relate this period to the reaction time, the time between the first action potentials and the actual arm movement, and the force put into the reaction (as indicated by the slope of the arm movement line), but have so far found no other factor in the reaction with which it correlated.

No clear relation was found between the time to the first action potentials (reduced reaction time) and the period from there to the actual arm movement. Nor could the former interval be related to any other time measures, or to the force of the reaction.

There is some relation, however, between the interval from the first action potentials to the initiation of movement in the arm and the force of this movement. This should be expected since this time is undoubtedly in part a result of the inertia of the forearm which inertia will be more quickly overcome by a more forceful muscular contraction.

Figure 1 also illustrates a phenomenon that was discovered incidentally to the above study. It was found that if one or both of the muscles were in a partial state of contraction before and during the reaction period there very commonly occurred an inhibition of this contraction in both muscles, this inhibition being followed by the usual contraction period. Such a partial contraction occurred accidentally at first, and was later experimentally set up by having the subject flex or extend the arm somewhat beyond the neutral point, thus requiring some action of the corresponding muscle. As a further check upon the appearance of this inhibitory period, we also placed a weight against one of the muscles, and allowed the arm to start from the usual neutral position. The results in this case were the same, though the frequency of records showing inhibition was lower. The time taken to the appearance of inhibition after the stimulus was highly variable. In some cases the time ran as low as 30 sigma, but for the most part approximately 100 to 115 sigma. It must be remembered that this reaction of inhibition commonly occurred in both muscles if both were contracting. In case only one muscle was contracting, it would appear in that one, whether it were the reacting muscle or its antagonist.

We have checked the appearance of this inhibitory period by using different lengths of warning periods, by employing different stimuli, and different subjects. Within the limits of our observations it appears to be a common, normal occurrence in this reaction. On some subjects it appeared nearly

always and on others it was found in about one of three records. With one subject we were unable to obtain a satisfactory record showing it, but several of these records presented doubtfully positive pictures. We were unable to determine what factors would increase or decrease the frequency of its appearance. When it failed to appear the reactions were of the usual sort except that the preliminary contraction in the muscles merely enlarged with the onset of the reaction proper.

Discussion

The variability of the findings of these experiments is probably due in large part to our inability to weight properly such factors as varying speed of reaction, varying force put into the reaction, and the usual variations in the conditions for reactions of even this simple type. We may say, however, that it seems to us highly improbable, even with further elaborate study of these reactions, that any clear sequence can be given with reference to these findings which will permit the prediction of what will occur in any given reaction. A possible exception to this apparent independence of factors is the relationship, mentioned above, between the time from the first action potentials to the beginning of arm movement and the force of the contraction.

The phenomenon of 'pre-inhibition' of a previously contracting muscle is of interest. It demonstrates the possibility of an efferent chain of events observably extending from reflex time up to the appearance of voluntary contraction in simple reactions.

Summary

1. The antagonistic muscles, triceps and biceps brachii, show a small difference in the time of initiation of contraction for a simple voluntary extension or flexion of the forearm.

2. This difference appears to be of the order of 7 sigma varying from 0 to 29 sigma.

3. This difference is not clearly related to any other factors in the reaction sequence.

4. The muscle which is to bring about the reaction is the first to initiate contraction.

5. The period between the initiation of action potential in the muscles and the point at which the arm actually begins to move is related to the force of the contraction.

6. It was found that if either or both of the muscles were in a state of partial contraction at the time of the stimulus, they were in many cases inhibited before the onset of the muscular contraction.

7. This inhibition, though normally occurring within sbout 100 sigma, at times appeared very early—up to 30 sigma after the presentation of the stimulus.

8. We could find no conditions which would determine the appearance of this inhibition, and can only state that it seemed to be a common characteristic of such responses.

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AN 'APPARENT MOVEMENT' PUZZLE

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Recently a small and inexpensive toy which utilizes the Phi phenomenon has appeared on the market, under the name of 'Yogi.' It is so constructed that a Fakir appears to pass a sword through a solid pin which represents the neck of a girl. The puzzle is about the size and shape of a cheap watch. The sword takes the place of an hour hand, while the Fakir and the body of the girl are pictured on what would be the dial. The head and neck of the girl are stamped out of sheet metal, and may be inserted in a hole passing through glass, dial, and case, so that the neck projects up from the pictured body, directly in the path of the sword. The neck passes through the picture at a point corresponding to the numeral '9' on a watch, while the sword normally rests at '8.' By moving a lever a spring is first compressed and then suddenly released, moving the sword rapidly in a counter-clockwise direction to '10.' The movement is so rapid that the sword seems to move through the shorter clockwise interval, despite the fact that it would have to cut the pin to do so. The resulting illusion is extremely compelling, and quite baffling, even to some who understand the laws of apparent movement.

A number of psychologists to whom I have shown the puzzle have expressed a desire to purchase the toys for class use. The manufacturers (Louis Marx & Co., N. Y.) have informed me that they are no longer making 'Yogi,' but suggest that they may be obtained from F. W. Woolworth Company stores, or from a jobber, The Franco-American Novelty Co., 1209 Broadway, N. Y. The toy sells at retail for a dime, but it is much more substantial than the price would indicate, and should last for many years.